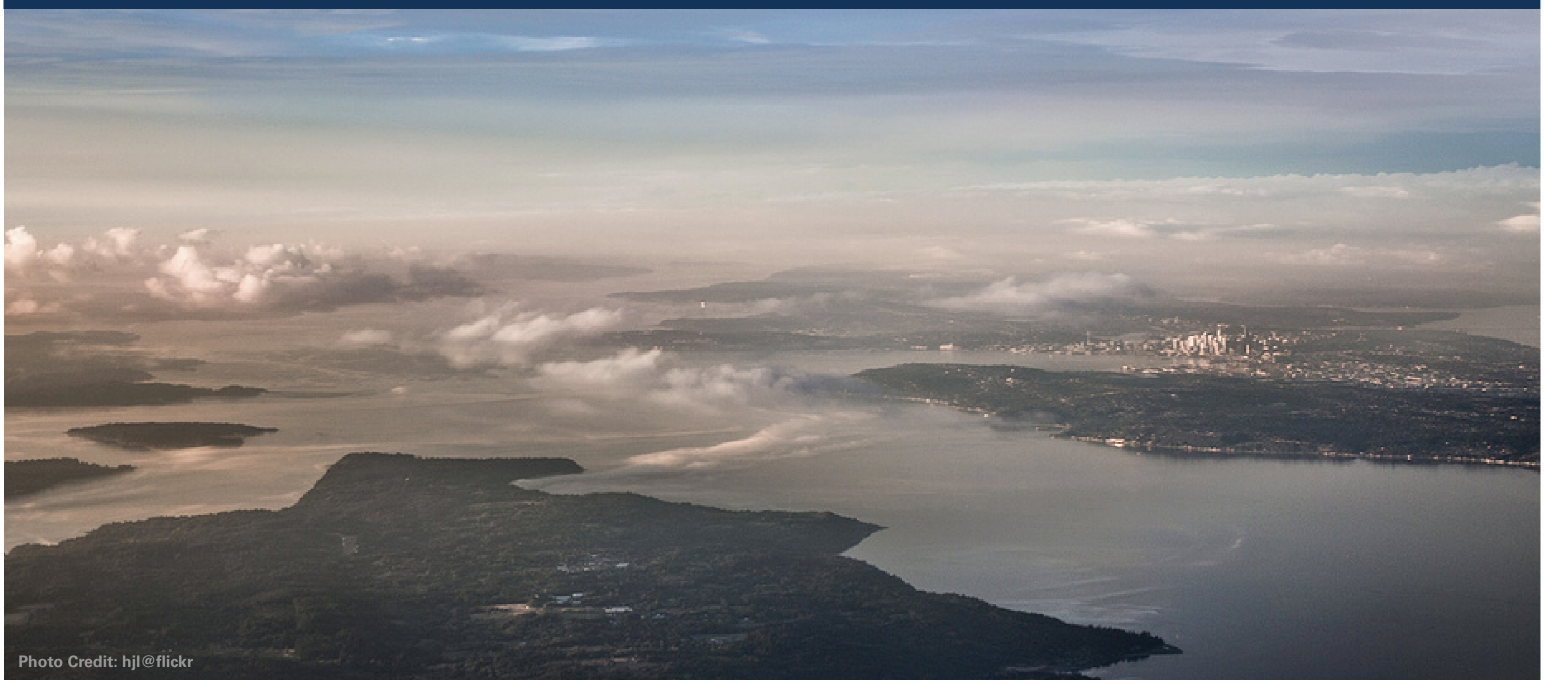
Biennial Science Work Plan for 2014-2016:

AN ASSESSMENT OF PRIORITY SCIENCE FOR RESTORING AND PROTECTING PUGET SOUND, WITH RESEARCH PRIORITY RECOMMENDATIONS FOR THE NEXT BIENNIUM

Puget Sound Partnership Science Panel
Puget Sound Partnership Technical Report 2014-03 | December 2014



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At its December 10, 2014 meeting the Leadership Council adopted this 2014-16 Biennial Science Work Plan as an official document of the Puget Sound Partnership.

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Executive Summary

Every two years, statute requires the Puget Sound Partnership to produce a *Biennial Science Work Plan* (BSWP). Its primary purposes are to I) assess how well ongoing research addresses decision-critical uncertainties relating to the recovery of Puget Sound; II) identify additional science needs for recovery; III) make recommendations for priority science actions in the coming biennium; and IV) suggest how science can better support recovery. This document is the third BSWP to be produced in the series, covering the 2014-2016 biennium. The four parts are summarized as follows:

Part I. Assessment of ongoing and recently completed research

To assess how well research addresses decision-critical uncertainties for recovery, an inventory was compiled of ongoing and recently completed research projects relating to the recovery of Puget Sound. Complete or partial information was collected for a total of 181 projects, including title, a brief description, start and end dates, total budget, and funding source. Of 181 projects in the inventory, 51% were funded by EPA, and 46% by other sources (4 were not funded). Mean budget size for projects funded by EPA was $338,826, and $228,797 for projects funded by other sources. Total expenditure on science was estimated to be in excess of $50 million, spread unevenly over a period of 7 years (2009-2016), or about $7 million per year. For projects featured in the inventory, mean start date was June of 2011, and mean end date is December of 2014, an interval of 42 months. It is intended that this inventory be used to summarize and synthesize knowledge, integrate strategies and actions, identify potential collaborators and groups of scientists working on related themes, and identify potential funding sources.

Where possible, each project was subjectively assigned to the most relevant of 48 Priority Science Actions (PSAs) that were defined as decision-critical for recovery in the previous (2011-13) BSWP. All but two of the 181 projects could be assigned to one of the 48 Priority Science Actions. The maximum number of projects assigned to a PSA was fifteen. Although five PSAs were assigned no projects and / or no funding, further scrutiny found that all five have in fact received either funding or attention, or both. We conclude that ongoing recovery science does broadly address recovery science priorities as they are stated in the 2011-13 BSWP. Taken together, they encompass the wide scope of scientific needs appropriate to recovery of an ecosystem as large and complex as Puget Sound.

However, further assessment of how well projects met needs defined by PSAs, and of unmet needs, was precluded. This was largely because, for most PSAs, goals were not sufficiently specified, nor were criteria that would indicate whether goals had been met. An attempt was made to identify candidate PSAs to be dropped from the list of 48 PSAs on grounds that their goals have been attained. No PSAs qualified for elimination, but this was not for lack of scientific progress, rather, largely because PSAs were not specific enough to support a decision. A consequence is that, as currently written, the list of PSAs can more easily grow than shrink.

While only 45% of projects in the inventory have been completed, the imagined impact of at least 181 research projects focusing on such a diverse array of recovery priorities engenders hope that recovery gains will be forthcoming. However, it also generates expectation, justified or not, that we will have a clearer vision of how recovery should proceed, and a better understanding of why recovery progress has been slower than expected. The fact that we currently have neither amplifies the need for advances in discovery that arise from research to be more directly and efficiently applied to the recovery of Puget Sound.

Part II: Description of recommended studies

To assess consensus about research priorities relating to Puget Sound recovery a total of 265 recovery scientists and practitioners were invited to recommend research priorities. Only 18 (6.8%) responded, with a total of 87 recommendations. Compared to ongoing and recently completed research, which emphasized toxics and pollutants, frequently recommended projects addressed issues relating to ocean acidification, marine and nearshore habitats, social sciences, ecosystem monitoring. These differences may reflect changing emphases in research relating to recovery, in particular, emphasis on ocean acidification.

Part III: Studies recommended in recent reports

To research recommendations from individuals (Part II) were added recommendations from reports written in the last biennium (listed below). No process currently exists for prioritizing recommendations for recovery research, whatever their provenance. Accordingly, no attempt was made to select or rank recommended priorities for research. Rather, recommendations were presented in order of apparent degree of validation (the formality of the process used to derive recommendations, whether or not that process was documented, and the implied extent of consensus among experts).

- A subset of 11 recommendations from 19 in the report by the Blue Ribbon Panel on Ocean Acidification;
- 24 research priorities relating to the Salish Sea Marine Survival Project;
- 7 recommendations from a report on forage fish;
- 42 research gaps from a report on priorities for social sciences;
- 56 monitoring gaps identified by work groups of the Puget Sound Ecosystem Monitoring Program.

Prospective sponsors of recovery science in Puget Sound should view this as a list of relevant and timely research, all backed by the credibility of scientists currently working on ecosystem recovery in Puget Sound but many lacking support from or knowledge of policy makers.

Part IV: Recommendations for improvement

According to the latest *State of the Sound* report (2013) we are half way to the statutory 2020 'deadline' for recovery, but most status and trends indicators ('Vital Signs') have not advanced much, if at all, towards their targets, and some, such as orcas, have lost ground. Puget Sound recovery practitioners are not alone in expending great effort and still finding recovery elusive. A recent meeting of lead scientists representing Puget Sound and six other large coastal ecosystems in the US revealed that all were struggling with this challenge.

Additional lessons from the workshop were that progress toward specified goals tended to be greater in recovery strategies that focus on fewer targets, and are more explicitly model-based. Regarding the first, progress in Puget Sound may be imperceptible because capacity and resources are spread too thinly over too many targets and across too large an area for recovery gains to be detectable. Even if this is true, in complex systems like Puget Sound, narrowing the scope of the recovery strategy to a feasible yet functionally effective number of targets turns out to be one of the greatest challenges of all. This is because the number of potential targets is large, many of them interact with each other, and much of the information required to rank targets by potential to yield greatest recovery gains is lacking. The second (utility of models) is partly a consequence of the first. It is evident from this assessment that models are reasonably prevalent among ongoing and recently completed *research* projects in Puget Sound, yielding critical insights into ecosystem processes. But this is less true of recovery strategies. Too often it is left implicit how results from research (especially models) will influence and be applied to recovery.

These and other reasons that might account for little observable progress towards recovery are all symptoms of a more inclusive explanation: that adaptive management (AM) is difficult to apply at the ecosystem level. No process guarantees achievement of recovery goals, but AM is the approach that, more than any other, improves the likelihood that progress can be made towards recovery under uncertainty. Practitioners at the workshop agreed that applying AM to large and complex ecosystems is challenging, but nonetheless re-affirmed unanimously that AM should remain the default approach to recovery, for three main reasons: there are too many unknowns for any alternative approach to be viable; to chart a cost-effective course towards recovery; and to demonstrate net benefits of actions in order to justify continued funding for recovery (or, if actions do not deliver desired effects, at least to understand *why*). Discussion about relative expenditure on monitoring and AM among ecosystems revealed an average of about 15% of the total spent on recovery. This was an amount limited more by amounts funding agencies were prepared to commit than by what is needed to address critical uncertainties.

In Puget Sound, AM was nominally adopted as the default approach, but AM has been applied in a patchy and incomplete manner, partly because of insufficient resources. The Science Panel endorses application of AM, and recommends that it be supported accordingly. Initial emphasis should be on completion of ‘implementation strategies’ for each target. These would include conceptual models that describe the mechanistic theories, causal pathways, and actions by which recovery targets are expected to be met, and are a key step in the programmatic cycle of AM. If everything were known about how to achieve a given recovery target, the implementation strategy would resemble, say, a plan to build a bridge. For ecosystem targets, however, it is rarely the case that enough is known, and no new knowledge is needed, to attain a recovery goal. For most, there is uncertainty about how outcomes are affected by natural processes, how these are impacted by humans, or how restoration and protection actions bring about recovery. In this context, therefore, the term ‘implementation strategy’ includes and entails the integration of science to address critical uncertainties.

Used in this way, implementation strategies should address and resolve many of the difficulties relating to identification and selection of decision-critical research that were highlighted in Part I of this report , provided those implementation strategies provide a agreed upon roadmap for policymakers. Once an implementation strategy is designed and documented it becomes possible to separate layers showing the junctures at which (1) research is needed to resolve a critical uncertainty (including models and social science), (2) monitoring is needed to assess effectiveness of actions, (3) policy changes are required; (4) costs can be estimated to assess cost-effectiveness, and (5) time will be needed for social and ecological processes to deliver expected outcomes. In this way, not only are the essential elements of recovery (science, policy, monitoring, etc.) featured, but their interactions can also be represented. For any given time and purpose (such as the preparation of a BSWP), the list of research priorities can be drawn up simply by combining the 'research layers' from each implementation strategy. The list of monitoring and policy priorities would be similarly derived. It becomes at least conceivable to estimate and compare the cost and cost-effectiveness of alternate paths and actions, order actions into a logical time frame, and expose common and conflicting goals within and among strategies.

It is further recommended that implementation strategies be designed by a separate 'recovery group' for each target. Finally, once implementation strategies have been defined and documented, funds should be awarded largely to projects – be they for research or implementation of recovery-related actions – that explicitly describe how topics featured in and justified by implementation strategies will be addressed. The next BSWP should summarize progress in the design and use of implementation strategies, including the identification of recovery research priorities, and descriptions of criteria by which attainment of research objectives will be assessed.

Conclusions and outlook

The emphasis on creating implementation strategies by separate recovery groups is intended to meet several needs. One is to integrate science and policy more directly into the practice of recovery. A third is to specify strategies (that can be supported by policy) for attaining each recovery target, while implementing a style of adaptive management that is more informative about effectiveness and progress. The second need is to find additional ways to advance the research agenda to define decision critical science for recovery, given the wide array of what are essentially equal priorities, and in the face of shrinking budgets. The only way to achieve this exacting agenda is to spread the task of planning recovery strategies and guiding their implementation among groups of practitioners with the requisite experience and resources.

Until funds can be allocated to recovery groups, progress is expected to be limited. Even then, this approach to defining implementation strategies will test the limits of volunteerism. It is expected that several nascent recovery groups will explore the feasibility of this approach over the next year or two. The Science Panel will support these groups on issues relating to science and decision-making, and help to record their collective experiences accumulated during this exploration period, for the benefit of those that follow.

Creation of recovery groups would mark the fourth time that the effort of recovering Puget Sound has been subdivided (salmon recovery divides effort among 16 watershed groups, coordinated research and actions are divided among six Lead Organizations or LOs, and the task of integrating recovery planning and implementation is divided among nine Local Integrating Organizations, or LIOs). Ultimately, efficiencies should increase with coordination and alignment among these potentially intersecting paths, but no purposed mechanism (such as a steering committee) exists to steer and guide them. If and when a critical number of recovery groups deliver and begin to oversee implementation of recovery strategies, a level of coordination will be required that does not yet exist in Puget Sound, requiring capacity that includes but goes well beyond science.

Finally, a summary of needs relating to recovery science that were expressed in this document is given in the table below.

	A list of needs relating to recovery science in this BSWP.
1	For a process to be developed by which the inventory of recovery research projects can be continuously updated (as opposed to recreating it anew every biennium) using a dedicated online database. Once operational, funding agencies should require grantees to enter project data into the database as funds are awarded.
2	For the BSWP to be published as far in advance of other work plans (including LO plans and Action Agenda Updates) as necessary to allow research recommendations to be acted upon, and funding provisions made (>6 months).
3	For sponsors of recovery research to consider recommendations and priorities listed in Parts III and IV of this document.
4	For effectiveness of recovery actions to be assessed, where appropriate, through effectiveness monitoring.
5	For *cost effectiveness* to guide planning and implementation of recovery priorities and actions.
6	For Priority Science Actions and their goals to be made sufficiently specific to permit assessments of progress.
7	For the scope of Puget Sound's recovery strategy (e.g. number of recovery targets) to be reduced, and / or funding to be increased, such that resources are sufficient to allow Adaptive Management to be applied to every target.
8	For 'implementation strategies' to be defined and documented for every target by a separate 'recovery group'.
9	For the PSP Science Panel to support the definition, characterization, and description of 'implmentation strategies'.
10	For results and findings of completed research projects to be synthesized and their implications for recovery assessed, focusing initially on recovery targets for which implementation strategies are to be prepared.
11	Where appropriate, for scientists conducting recovery research to be actively involved in the process of transforming their research results to actions, expecially in the design of implementation strategies by 'recovery groups'.
12	For Structured Decision Making to be applied in the design of implementation strategies where consensus among experts is elusive.
13	Once implementation strategies have been defined and documented, funds should be awarded largely to projects – be they for research or implementation of recovery-related actions – that explicitly describe how topics featured in and justified by implementation strategies will be addressed
14	For RFPs relating to recovery science to require proposers to describe how their projects will address PSAs (and elements of implementation strategies), and how results will be applied to recovery.

Introduction

The Puget Sound ecosystem is the geographic region defined by the contiguous watersheds of 14 major rivers that drain into the marine waters of Puget Sound (about 35,500 km^2). It forms the southern half of the Salish Sea Ecosystem, a trans-national region that includes watersheds draining into the Strait of Georgia in Canada. Approximately 4.3 million people live around Puget Sound, most in the Seattle metropolitan area and city of Tacoma, the remainder in scores of smaller cities, towns, and rural communities scattered across parts of 12 counties. More than 150 years of expanding settlement, agriculture, industry, and development have taken their toll on the natural resources, ecosystem services, and abundance of species like salmon that have long supported people in the region (Lombard 2006, Ruckelshaus and McClure 2007).

Efforts to clean up the Sound and where possible restore its ecological health and functionality have gained momentum over the last two decades. The current program was initiated by the Washington State Legislature in 2007, which created the Puget Sound Partnership (PSP) to coordinate recovery. Stipulating that recovery should be based on and informed by science, the legislation specified an organizational structure for PSP that includes a panel of scientists (Science Panel or SP) to advise the governing Leadership Council (LC) and the Ecosystem Coordination Board (ECB) on issues relating to science (RCW 90.71). Members of the SP represent a wide range of disciplines relating to the status, natural dynamics, pressures on, and recovery of the Salish Sea ecosystem.

The principal role of the Science Panel is to define, facilitate, and oversee scientific support for the recovery strategy, helping to ensure that the recovery process is based on and informed by science. This includes, for example, providing scientific analyses for prioritization and setting of recovery goals.

Recent accomplishments in scientific support of Puget Sound ecosystem recovery include:

- A pressures assessment methodology developed by a Science Panel subgroup (Labiosa et al. 2014) was used to implement an assessment of the critical vulnerabilities of Puget Sound's freshwater, marine-nearshore, and terrestrial resources (McManus et al. in prep)
- The 2014 Salish Sea Ecosystem Conference spurred learning by more than 1,200 participants who chose from among 450 oral presentations during eight concurrent sessions and viewed more than 200 posters.
- The 2011-13 Biennial Science Work Plan was used to guide funding discussions and decisions by EPA's Office of Research and Development and Washington Sea Grant
- The 2013 State of the Sound reports on progress toward ecosystem recovery using the Partnership's vital sign indicators
- Social scientists have collaborated to prepare a special issue of Coastal Management on social science in support of Puget Sound ecosystem recovery
- New knowledge and understandings about:
    - Human wellbeing indicators for Hood Canal
    - Human contributions to low dissolved oxygen concentrations in Puget Sound's marine waters
    - Stormwater treatment effects on pre-spawn mortality of coho salmon
    - Importance of small lowland streams (e.g., for Chinook salmon)

- Critical growth periods for outmigrant Chinook salmon
- Effects of dam removal on the Elwha River and associated nearshore systems
- Changes in diet of generalist and specialist marine birds
- Habits and diet of southern resident killer whales away from the Salish Sea

To help guide and propagate scientific support for recovery, statute requires the Science Panel to produce, every two years, a *Biennial Science Work Plan* (BSWP; Appendix A). Its primary purposes are to (1) assess how well ongoing research addresses uncertainties relating to the recovery of Puget Sound; (2) identify additional science needs for recovery; (3) make recommendations for priority science actions in the coming biennium; and (4) make recommendations for improving the collective scientific effort contributing to Puget Sound recovery. This document is the third BSWP to be produced in the series, covering the 2014-2016 biennium.

Focus and structure of the 2011-13 BSWP

The previous edition was entitled *Priority Science for Restoring and Protecting Puget Sound: A Biennial Science Work Plan for 2011-2013* (herein referred to as the 2011-13 BSWP). Its principal goal was to identify, in the ongoing program for Puget Sound recovery, where progress was hindered by a lack of scientific understanding or information, and, by implication, where research would yield the greatest gains.

Restoring and protecting an ecosystem as large and complex as Puget Sound demands a strategic program of proportional size and complexity. At the outset, there is no readily available shortlist of targets and actions that would most efficiently lead to recovery. Similarly, there is no straightforward way to objectively identify and prioritize research. The greatest asset for recovery may be the large community of scientists, resource managers, environmental practitioners, policy makers and other stakeholders who live and work in the region on recovery-related issues. Collectively, they possess the understanding and information about the ecosystem needed to guide its restoration: its history, the diverse pressures and mechanisms that have led to its decline, the actions likely to reduce those pressures and promote recovery, and where the critical uncertainties lie. It was by drawing on this collective awareness that the master plan for Puget Sound recovery and management, the *Action Agenda,* was developed. Currently in its 3rd revision, the *2014-15 Action Agenda for Puget Sound* describes the strategies, sub-strategies, and specific near-term actions that are intended to restore and protect key components and attributes of the Puget Sound ecosystem, and the services they provide.

A consensus approach was also used to develop a list of priority science actions (PSAs) for Puget Sound recovery that was published in the 2011-13 BSWP and to identify the subset of these priority actions that the Science Panel would focus on achieving. Initially, a list of gaps in scientific knowledge about the ecosystem was drawn up, based on input from three sources: a review of the questions that current research and monitoring were addressing, a review of recommendations from scientific reports and publications on the science needs for a program of ecosystem recovery in Puget Sound, and recommendations from a broad base of scientists, practitioners, stakeholders, and decision makers. Analyzing this information relative to a conceptual model of ecosystem recovery for Puget Sound illustrated where gaps in scientific attention and knowledge were likely present. Importantly, not all identified gaps in knowledge became research priorities. Those that qualified did so by satisfying two further criteria: that scientific uncertainty was not only high, but also ‘decision-critical’, that is, it hindered progress in restoration and recovery.

Ultimately, 48 conceptual topics were nominated as PSAs (Table 1). These were organized into the same structure as the *2012/2013 Action Agenda* under four principal strategy areas: A. Protect and Restore Terrestrial and Freshwater Ecosystems, B. Protect and Restore Marine and Marine Nearshore Ecosystems, C. Reduce and Control the Sources of Pollution to Puget Sound, and D. ‘Other’, including emerging issues like Climate Change and Ocean Acidification, and Human Dimensions.

The list of PSAs was intended to be used by federal, state, and non-governmental funding agencies to focus research and environmental monitoring on science within their areas of responsibility (e.g., clean water, endangered species, land conservation, transportation, etc.) that would be of greatest relevance to recovery. The Science Panel reviewed the list of 48 PSAs to identify a subset of actions that they identified as critical for their attention.

Focus and structure of the 2014-16 BSWP

When planning the 2014-16 BSWP in mid-2013, the Science Panel determined that the statutory requirements should be met by describing how well ongoing research addressed the 48 PSAs listed in the 2011-13 BSWP. Accordingly, in the preparation of this document, an inventory of recently completed and ongoing research projects was compiled and, where possible, each was subjectively assigned to the most relevant of the 48 PSAs listed in the previous BSWP, as a first step towards evaluating the relevance of ongoing research to recovery. Presentation of PSAs in the 2011-13 BSWP was deliberately structured to correspond with the layout of strategies and sub-strategies in the *2012/2013 Action Agenda.* The same organizational framework was retained in this edition.

Table 1. Priority Science Actions (PSAs) from the 2011-13 Biennial Science Work Plan

Action Agenda Focus Area	Action Agenda Strategy	PSA No.	Priority Science Action
PROTECT AND RESTORE TERRESTRIAL AND FRESHWATER ECOSYSTEMS			
Habitats	A1 A2 A3	1	Develop analytical tools to identify options for where to protect, where to restore, and where to develop while maintaining desired ecological goods and services.
		2	Use social science to guide development of adaptive management structures that can effectively linkrestoration science to management decision making.
		3	Develop ecological indicators; assess baseline conditions; and implement monitoring to measureecosystem function relative to no net loss.
		4	Conduct social science studies to describe the key institutional challenges to attaining no net loss andimprovements from restoration.
Floodplains	A5	5	Estimate the value of floodplains in terms of the ecosystems services they provide.
		6	Develop key ecological indicators and implement monitoring to assess status of floodplains.
		7	Improve understanding of the effects of vegetation on dikes and other flood control structures.
Species and Foodwebs	A6	8	Develop analytical tools to evaluate whether strategies to address factors limiting the productivity ofsalmon are being implemented in the most effective combinations, at the right times, and with appropriate amounts of effort to lead to recovery.
		9	Identify the causes of apparent decline in marine survival of salmon as they leave their natal rivers and exit Puget Sound.
	B5	10	Assess risks imposed by terrestrial and freshwater invasive species.
Freshwater	A7	11	Develop robust ecological indicators and implement comprehensive monitoring for stream flows.
		12	Evaluate and improve stream flow targets in terms of their effects on abundance, productivity, distribution, and life history diversity of salmon.
PROTECT AND RESTORE MARINE AND NEARSHORE ECOSYSTEMS			
Habitats	B2 B3	13	Develop analytical tools to identify priority areas for protection, restoration, and stewardship.
		14	Develop adaptive management structures that link restoration science to management decision making
		15	Identify the key stressors on eelgrass.
Species and Foodwebs	B5	16	Develop analytical tools and information to understand the tradeoffs in managing foodwebs of marinespecies and the multiple stressors affecting those foodwebs.
		17	Implement biological and sociological studies to understand the conservation and sociological roles ofmarine protected areas for habitat and species protection, ecosystem restoration, and sustaining usualand accustomed tribal fishing areas.
		18	Implement studies to identify stressors on forage fish.
		19	Implement studies to understand the causes of declines in marine bird abundance.
		20	Conduct studies to identify sources of nutrients that enter Puget Sound that can be used to develop strategies for maintaining water quality for Puget Sound foodwebs.
		21	Assess risks imposed by marine invasive species.
REDUCE AND CONTROL SOURCES OF POLLUTION TO PUGET SOUND			
Contaminants	C1	22	Implement studies on persistent, bioaccumulative chemicals to understand transport, trophic transfer, and associated ecological and human health risk and to ensure that Washington State's water quality standards and sediment management standards are protective of both fish and wildlife and allowhuman and wildlife consumption.
		23	Describe the availability, feasibility, and safety of alternatives to products and processes that use andrelease toxic chemicals of concern into the Puget Sound ecosystem.
		24	Develop integrated monitoring and assessment of toxic chemical sources, exposure, and effects.
		25	Synthesize information on emerging contaminants of concern.
Runoff from the Environment	C2	26	Develop monitoring and assessment of benthic invertebrates in small streams to evaluate stormwater management and other efforts to protect and restore streams.
		27	Evaluate the effectiveness of low impact development (LID) projects and stormwater management best management practices and programs.
		28	Evaluate land uses and associated pollutants that would require treatment beyond sediment removal.
		29	Evaluate projected environmental benefits of structural stormwater retrofits given varying levels of effort to guide the extent of structural retrofits needed to help meet 2020 ecosystem recovery targets.
		30	Evaluate individual and combined effects of commonly used pesticides on salmonids, other fish, and their foods
Wastewater	C5 C6	31	Evaluate nitrogen reduction in public domain on-site system treatment technologies.
		32	Implement studies of human-related contributions of nitrogen to dissolved oxygen impairments insensitive Puget Sound marine waters.
Shellfish	C7	33	Establish and sustain pollution identification and correction (PIC) programs to identify and fix nonpoint pollution problems.
		34	Research and implement monitoring to understand the specific environmental conditions that produce toxic harmful algal blooms (HABs) and pathogen events.
Oil Spills	C8	35	Evaluate existing oil spill risk assessments and complete additional risk analyses of higher risk industrysectors to ensure there are appropriate levels of investment in reducing risk.
		36	Evaluate information on baseline conditions for key species at risk from oil spills and improve these asnecessary so that baselines exist that can be used in assessments of natural resource damages.
Cumulative Water Pollution	C9	37	Expand monitoring of freshwater and marine water areas to assess human exposures to pollution during water contact recreation.
OTHER			
Emerging Issues G Ocean Acidification		38	Design and implement monitoring for ocean acidification variables across the Puget Sound tounderstand the status, diversity and range of conditions.
		39	Develop and implement studies to assess the risk and vulnerability of Puget Sound species to oceanacidification.
		40	Develop adaptation strategies given assessed vulnerability to ocean acidification.
Scientific Tools for Informing Policy	D1	41	Conduct institutional analyses of the overall governance and management structures in which PugetSound recovery strategies operate.
		42	Conduct integrated risk assessments of the impacts of different pressures on the Puget Soundecosystem.
		43	Develop a systematic, transparent, and ecologically based prioritization tool for near-term actions inthe Action Agenda that will support evolutionary learning and adaptation.
Coordinated Ecosystem Monitoring	D3	44	Implement and sustain a comprehensive, coordinated monitoring program to understand the status ofthe Puget Sound and the effectiveness of recovery actions.
Human Dimensions in Ecosystems	D7	45	Develop assessments of ecosystem services to help decision makers make informed decisions aboutrestoration and protection.
		46	Develop socioeconomic indicators to help measure and report on the human dimensions in ecosystem recovery.
		47	Conduct a baseline literature review of social science research and a survey of data to identify resources and gaps that can be readily available and used by ecosystem recovery planners and practitioners.
		48	Evaluate the most effective combinations of regulatory, incentive, and educational programs for different demographics in Puget Sound.

Approach and Methods

This section of the 2014-16 BSWP describes how the two principal features of the BSWP – an inventory of ongoing research and an inventory of research recommendations – were compiled.

Inventory of projects

An inventory of ongoing and recently completed research was compiled by seeking basic information about projects that qualified by the following criteria: (a) the project was related to the recovery of Puget Sound, (b) it was entirely or largely scientific (as opposed to, say, implementing a recovery action), and (c) it was either ongoing or had ended after 2010. For each project the following information was sought: the project title, a brief project description, the name of the principal investigator or project contact, their phone number and email address, the name of the implementing institution, the project start and end dates, funding amount, funding source, and web addresses for available reports or publications.

The information was gathered in four ways. First, members of the Science Panel and PSP staff added projects they were familiar with. Second, one or more individuals involved in recovery research were contacted at each of the 34 institutions listed in Appendix B, and asked to provide project information. In some cases, one individual assembled information about all qualifying recovery research projects based at their institution. In others, multiple individuals from an institution were independently contacted about their own projects. Third, the required information was gathered from websites of those institutions (especially the state and federal agencies). And fourth, lead authors of 103 scientific papers and reports that were related to Puget Sound recovery, and published since 2011, were invited to provide information about ongoing or recently completed projects in which they were involved.

Where possible, each project was subjectively classified under the most thematically pertinent Priority Science Action, and these in turn were nested within a sub-strategy of the four principal strategic areas of the Action Agenda (as in Table 1).

Inventory of recommendations for recovery research

To develop the information presented in Part II of this document, an inventory of recommendations for science needed to inform Puget Sound recovery in the coming (2014-16) biennium was compiled primarily by using the same approach as was employed in the 2011-13 BSWP – scientists engaged in recovery research and recovery practitioners were asked to make recommendations about critical research needs. While no one can have a full or fully objective response, combined responses from a broad spectrum of those with an informed opinion should capture the priorities. Accordingly, a list of 265 names and email addresses was compiled from two sources: a) the primary authors of 150 scientific papers and reports relating to Puget Sound recovery that had been published since 2011 (Appendix F), and b) nominations from Science Panel members and others in the recovery community.

Respondents were invited to make as many recommendations as they liked, but were asked to base their selection on the same considerations that were applied to the selection of Priority Science Actions in the 2011-13 BSWP, namely:

- How much is known about a topic, and how much more do we need to know (what is the level of scientific uncertainty?).
- Where is a lack of scientific information hindering progress in recovery?
- What are the decision critical questions and information needed for ecosystem restoration and protection?

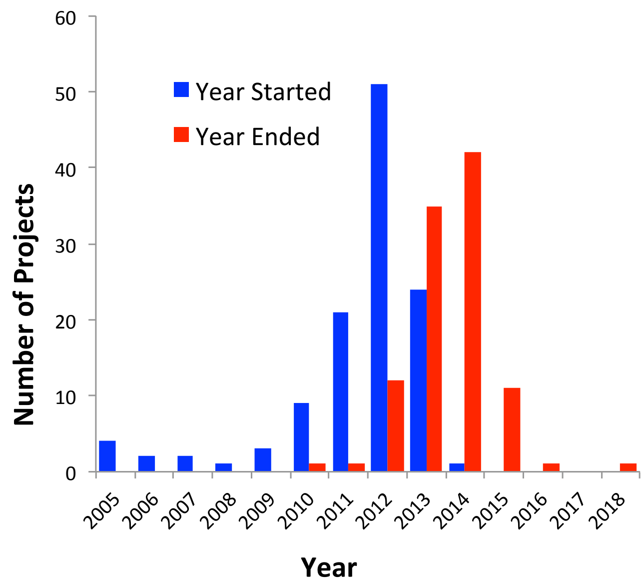
Respondents were asked to make a declarative statement defining the topic, briefly summarize its rationale and justify its inclusion. They were not asked *not* to recommend topics that were on the 2011-13 BSWP list of Priority Science Actions (PSAs), but they were invited to indicate which items should remain on or be removed from that list, and to provide rationale.

To develop the information presented in Part III of this document, the staff team supporting the production of the 2014-16 BSWP identified reports prepared in the last biennium that address some of the key topics highlighted by the Panel in the 2011-13 BSWP. Recommendations from these reports were presented in a spring 2014 draft of this document. Stakeholder review of the draft document suggested additional reports to be included in this portion of the inventory of recommendations.

Part I: Assessment of Ongoing and Recently Completed Research

This section describes ongoing and recently concluded research relating to the recovery of the Puget Sound ecosystem.

Complete or partial information was collected on a total of 181 research projects that were ongoing in the latter half of 2013, or had ended more recently than 2010. An inventory of these projects is presented in two formats: tabular, as Appendix C of this document, and online as a downloadable Excel file from: *http://www.eopugetsound.org/sites/default/files/features/resources/2014-16_BSWP_Appendices_C-F_Apr_2_2014.xlsx*. In all formats, projects are numbered P1-181. Appendix C1 features all project information except their descriptions, which are listed in Appendix C2 (separation of project descriptions was necessary for clarity of presentation in this document; separation was of course not necessary in the downloadable version).



Project timing and budgets

Of the 181 projects in the inventory, 93 (or 51%) were funded by EPA, 84 (46%) by other sources, and 4 were not funded. On average, projects featured in the inventory started in June of 2011, and are due to end in December of 2014, an interval of 42 months (Figure 1; long term monitoring projects were excluded from these estimates).

The average budget for projects funded by EPA was $338,826 (n=90, sd=$243,981; Figure 2). For projects funded by other sources, the average budget was $228,797 (n=30, sd=$147,689; the $5 million budget for project no. 29 was excluded from this estimate). These means were used to estimate budgets of projects in the inventory that lacked budget data, so that total expenditure on recovery research could also be estimated. Only 3 (3.2%) of the projects funded by EPA lacked budget data, so the corrected total expenditure by EPA on science ($31,510,818) is close to the uncorrected total. This was not true of the corrected total for non-EPA expenditure ($23,761,359) because most (63%) of the non-EPA funded projects lacked budget

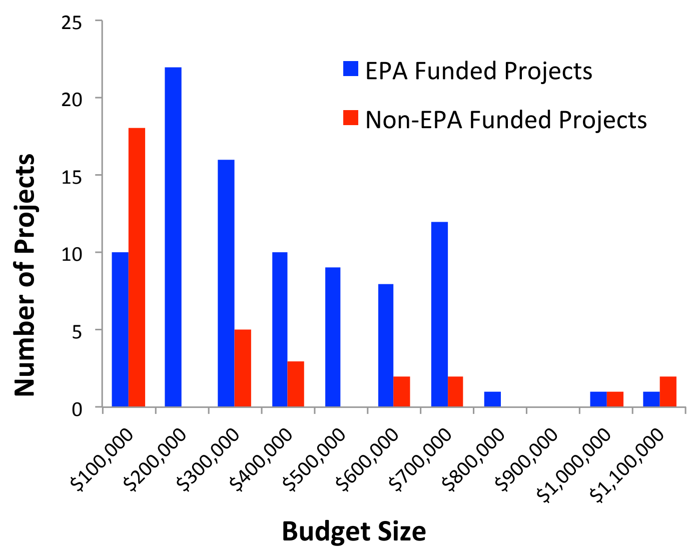


Figure 2. Distributions of budget sizes among EPA funded and non-EPA funded projects. The lowest category includes projects with budgets <= $100,000. The highest category includes projects with budgets >$1 million.

data. Combining these figures gives an estimate of total expenditure on recovery research in Puget Sound over the survey period: $55,272,177. Uncertainty about budgets of non-EPA funded projects may bias this figure, but given that the inventory is not exhaustive, the conclusion that total expenditure on recovery science during the survey period exceeded $50 million seems conservative.

Classification of projects among PSAs

All projects in the inventory could be assigned to one of the four principal strategic areas of the *Action Agenda*. Given the combined scope of the strategic areas, it would be surprising if this was not the case. Similarly, all but two of the 181 projects could be assigned to one of the 48 Priority Science Actions (the exceptions are project numbers 180 and 181). At face value, this suggests that ongoing recovery science is exceptionally well aligned with critical research needs. However, this outcome is also not surprising, for three reasons. First, 48 is a relatively large number of priorities, and many of them are broadly inclusive. Taken together, they encompass a wide scope of scientific needs. Second, assignment was not based on stringent criteria, but rather on whether or not a project fit the broad sense of a PSA. Third, the community of scientists and practitioners who were asked less than 3 years ago to suggest research priorities would have (and should have) nominated subjects they were familiar with, and in many cases, are still studying. Consequently, we should expect the probability of *not* being able to assign a project to a PSA to be small.

Judging from the total number of projects assigned to each PSA, research resources were not allocated evenly (Figure 3 and Appendix D). Some were well attended with up to 15 projects, while others appeared to be neglected (further scrutiny revealed that all received either funds or study, as summarized below). Given that the 48 PSAs differed in their degree of specificity, however, our 'null' expectation was not that each should have the same number of projects (equal to the mean of around 4 projects per PSA, derived by dividing 181, the total number of projects, by 48, the total number of PSAs). Rather, the null expectation was that the more 'generally' defined PSAs should have more projects assigned to them, and the more 'specific' PSAs fewer, than the mean. Subjective comparison of PSAs with the most projects and the least projects suggests that this expectation was supported. PSAs with the most projects (>9) and largest total allocation of funds (>$3,000,000), and those having 1 or 0 projects and <$300,000 are listed in Table 2 (all PSAs and assigned projects are listed in Appendix D). The latter tend to be not only more specific, but also to state goals that have more components and conditions than the former (their descriptions also tend to be longer). In the conditional sense, we should expect fewer projects to comply with their provisions, and this partly explains the pattern that was observed. Thus, if recovery science priorities were represented by a dartboard made with 48 sectors (PSAs) *of unequal width*, at which 181 darts (projects) where thrown, the distribution of darts in each sector would resemble the distribution of projects among PSAs in Figure 3.

Figure 3. Comparison of the total number of projects (black line), and the sum of their budgets (columns), for each of the 48 PSAs. PSAs were sorted by number of projects, then by total expenditure. They are color-coded by Action Agenda strategy: Terrestrial and Freshwater (green), Marine and Nearshore (blue), Pollutants and Toxics (red), and Other (yellow).

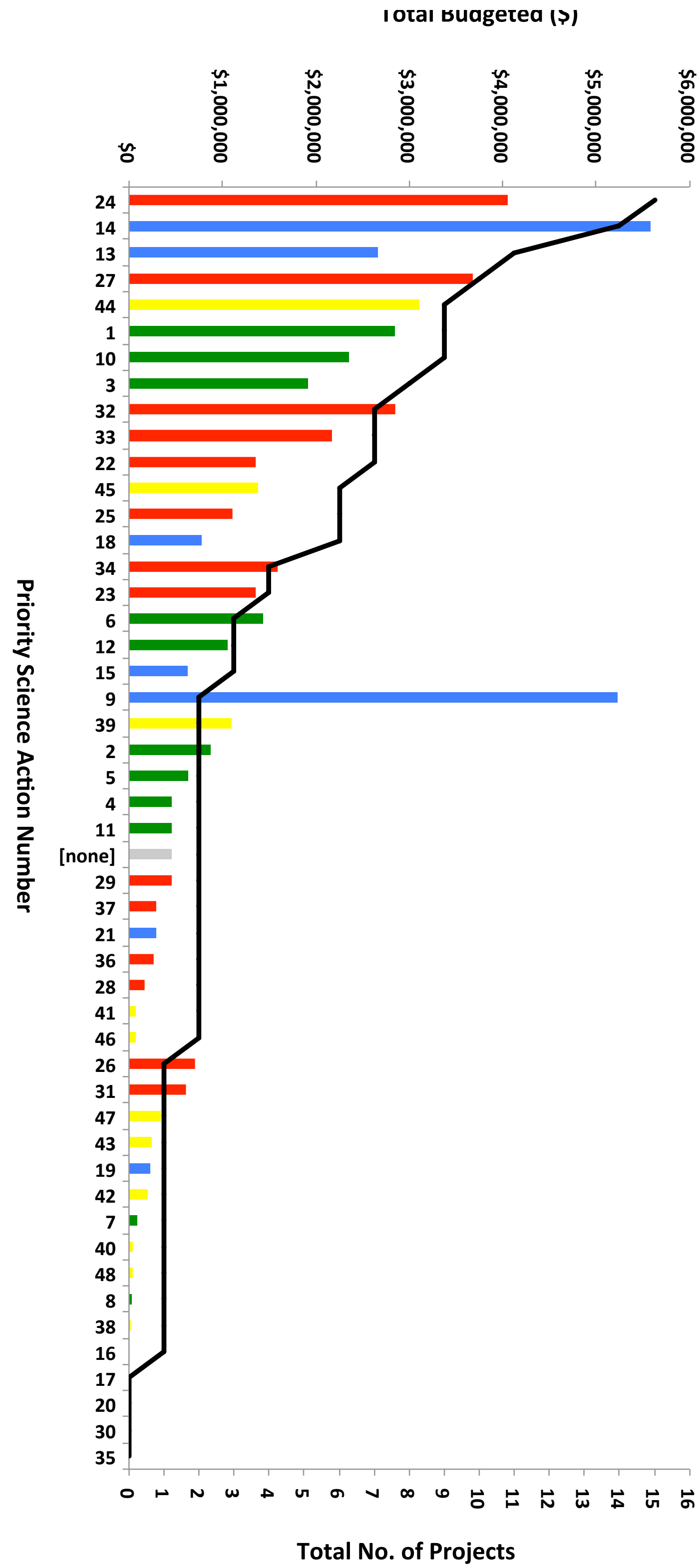


Table 2. PSAs with the most projects (>9) and total budgets (>$3,000,000), and those with the least projects (1 or 0) and budgets (<$300,000).

PSA No.	Priority Science Action title (from 2011-13 BSWP)	Total budgeted ($, corrected)	No. of Projects
	PSAs with the >9 projects and >$3,000,000		
24	Develop integrated monitoring and assessment of toxic chemical sources, exposure, and effects.	$4,051,104	15
14	Develop adaptive management structures that link [marine and nearshore] restoration science to management decision making.	$5,583,470	14
13	Develop analytical tools to identify priority areas for [marine and nearshore] protection, restoration, and stewardship.	$2,663,003	11
27	Evaluate the effectiveness of low impact development (LID) projects and stormwater management best management practices and programs.	$3,674,044	10
44	Implement and sustain a comprehensive, coordinated monitoring program to understand the status of the Puget Sound and the effectiveness of recovery actions.	$3,107,542	9
	PSAs with 1 or 0 projects, and <$300,000		
43	Develop a systematic, transparent, and ecologically-based prioritization tool for near-term actions in the Action Agenda that will support evolutionary learning and adaptation.[3]	$242,116	1
19	Implement studies to understand the causes of declines in marine bird abundance.	$228,797	1
42	Conduct integrated risk assessments of the impacts of different pressures on the Puget Sound ecosystem.	$200,000	1
7	Improve understanding of the effects of vegetation on dikes and other flood control structures.	$89,499	1
40	Develop adaptation strategies given assessed vulnerability to ocean acidification.	$40,000	1
48	Evaluate the most effective combinations of regulatory, incentive, and educational programs for different demographics in Puget Sound.	$37,500	1
8	Develop analytical tools to evaluate whether strategies to address factors limiting the productivity of salmon are being implemented in the most effective combinations, at the right times, and with appropriate amounts of effort to lead to recovery.	$30,408	1
38	Design and implement monitoring for ocean acidification variables across the Puget Sound to understand the status, diversity and range of conditions.	$20,000	1
16	Develop analytical tools and information to understand the tradeoffs in managing foodwebs of marine species and the multiple stressors affecting those foodwebs.	$0	1
17	Implement biological and sociological studies to understand the conservation and sociological roles of marine protected areas for habitat and species protection, ecosystem restoration, and sustaining usual and accustomed tribal fishing areas.	$0	0
20	Conduct studies to identify sources of nutrients that enter Puget Sound that can be used to develop strategies for maintaining water quality for Puget Sound foodwebs.	$0	0
30	Evaluate individual and combined effects of commonly used pesticides on salmonids, other fish, and their foods.	$0	0
35	Evaluate existing oil spill risk assessments and complete additional risk analyses of higher risk industry sectors to ensure there are appropriate levels of investment in reducing risk.	$0	0

Budget data in Figure 3, Table 2, and Appendix D estimate absolute and relative funding applied to each PSA. Total project funds were distributed among PSAs in a way that closely mirrored the distribution of projects (PSA 9 was an obvious exception, relating to causes of mortality in out-migrating salmon; of two projects assigned to PSA 9, project no. 29 will examine causes of salmon and steelhead mortality in the Salish Sea over the next 20 years). This pattern was also expected, not least because the two were not entirely independent (mean budgets were applied to projects for which budget data were lacking; see Approaches and Methods).

Assessment of how ongoing science addresses stated needs

Ranking PSAs by project number and total budget (Figure 3) provides only a crude measure of relative recovery effort expended on each PSA. It reveals nothing about whether support for a given PSA was *sufficient*. Nor does it mean that the five PSAs apparently receiving no funding in this survey were in fact unattended. Further scrutiny since conclusion of the survey found that all five have received either funds, or attention, or both, as summarized below:

1. PSA 17, the 'conservation and sociological roles of marine protected areas in Puget Sound' is being addressed by a Washington Sea Grant project entitled *Evaluating Puget Sound Marine Protected Areas to Increase Social Ecological Resilience* recently awarded to Patrick Christie at UW, in collaboration with PSP.

2. For PSA 20, a recent report on current and future sources of nitrogen into Puget Sound addresses 'sources of nutrients that enter Puget Sound that can be used to develop strategies for maintaining water quality for Puget Sound food webs':

   Roberts M., T. Mohamedali, B. Sackmann, T. Khangaonkar and W. Long (2014) Puget Sound and the Straits Dissolved Oxygen Assessment: Impacts of Current and Future Nitrogen Sources and Climate Change through 2070. Publication No. 14-03-007, Department of Ecology, State of Washington.

3. For PSA 30, a series of recent papers evaluated 'individual and combined effects of commonly used pesticides on salmonids, other fish, and their foods':

   Macneale, K.H., Spromberg, J.A., Baldwin, D.H., and Scholz, N.L. (2014). A modeled comparison of direct and food web-mediated impacts of common pesticides on Pacific salmon. Public Library of Science ONE, In press.

   Dietrich, J.P., A.L. Van Gaest, S.A. Strickland, M.R. Arkoosh. (2014). The impact of temperature stress and pesticide exposure on mortality and disease susceptibility of endangered Pacific salmon. Chemosphere, in press.

   Laetz, C.A., Baldwin, D.H., Hebert, V.R., Stark, J.D., and Scholz, N.L. (2014). Elevated temperatures increase the toxicity of pesticide mixtures to juvenile coho salmon. Aquatic Toxicology, 146:38-44.

   Jorgenson, B., Brown, L., Fleishman, E., Macneale, K.H., Schlenk, D., Scholz, N.L., Spromberg, J.A., Werner, I., Weston, D., Young, T.M., Zhang, M., and Zhao, Q. (2013). Predicted transport of pyrethroid insecticides from an urban landscape to surface water. Environmental Toxicology and Chemistry, 32:2469-2477.

   Laetz, C.A., Baldwin, D.H., Stark, J.D., and Scholz, N.L. (2013). The interactive neurobehavioral toxicity of diazinon, malathion, and ethoprop to juvenile coho salmon. Environmental Science and Technology, 47:2925-2931.

   Scholz, N.L., Fleishman, E., Brooks, M.L., Mitchelmore, C.L., Werner, I., Johnson, M.L., Schlenk, D., and Brown, L. (2012). A perspective on modern pesticides, pelagic fish declines, and unknown ecological resiliency in highly managed ecosystems. BioScience, 62:428-434.

   Weston, D.P., Asbell, A.M., Hecht, S.A., Scholz, N.L., and Lydy, M.J. (2011). Pyrethroid insecticides in urban salmon streams of the Pacific Northwest. Environmental Pollution, 159:3051-3056.

4. PSA 35 advises that existing oil spill risk assessments be evaluated, and additional risk analyses of higher risk industry sectors be completed 'to ensure there are appropriate levels of investment in reducing risk'. Grants of $150,000 in 2013 and $75,000 in 2014 from the State Toxics Account were awarded to PSP to address these issues. In collaboration with Ecology, PSP is evaluating existing Puget Sound marine transportation oil spill risk assessments, identifying gaps in marine safety, and working with experts to develop and apply appropriate risk reduction measures. PSP co-chairs the Vessel Traffic Risk Assessment (VTRA) Steering Committee with the Puget Sound Harbor Safety Committee, and oversees a VTRA contract with George Washington University. The Washington State Department of Ecology, US Coast Guard and Makah are co-leads guiding VTRA, with Ecology promoting integration and sharing of common data from other regional (pending) maritime transportation projects. The final VTRA report was completed on 3/31/14. The next stage of work is to review findings with those of other related analyses to refine and apply risk mitigation measures with maritime peers in Canada. Reports can be downloaded from: *http://www.seas.gwu.edu/~dorpjr/tab4/publications_VTRA_Update_Reports.html.*

5. PSA 16 advises that analytical tools and information should be developed 'to understand the tradeoffs in managing food webs of marine species and the multiple stressors affecting those food webs'. Two recent papers applied a preliminary modeling examination of this issue:

   Harvey, C. J., Williams, G. D., & Levin, P. S. (2012). Food web structure and trophic control in central Puget Sound. *Estuaries and coasts*, *35*(3), 821-838.
   Plummer, M. L., Harvey, C. J., Anderson, L. E., Guerry, A. D., & Ruckelshaus, M. H. (2013). The role of eelgrass in marine community interactions and ecosystem services: results from ecosystem-scale food web models. *Ecosystems*, *16*(2), 237-251.

   This topic appears to be the only PSA to have received no direct funding, and does warrant further attention, as described in Part III below under the section entitled *Ecosystem-based management of forage fish in Puget Sound*.

Ideally, further scrutiny would reveal how well projects meet the needs defined by PSAs, and expose unmet needs. However, such scrutiny was precluded by several factors. First, while most of the 181 projects in the inventory addressed one or more of the general topics captured by PSAs, few were specifically designed to address a given PSA (most projects were conceived before the list of PSAs was published; P29 was an exception). Assignment of projects to PSAs was possible, therefore, but only in hindsight, and only subjectively (different observers, even the same observer on different occasions, would assign projects in different ways). Second, for most PSAs, goals were not specified, nor were criteria that would indicate whether goals had been met. Extending the dartboard analogy, if the distance from the bulls-eye to a dart in the board relates to how well a project met a stated need, there is no ring around the center by which to determine that the bulls-eye was hit. Third, even if criteria had been provided, more than half (55%) of the projects in the inventory are ongoing and thus have no documented results or conclusions (Appendix D). Even if all projects were completed and documented, evaluating their 'success' without such criteria would require expert level familiarity with the subject, details, relevance, import, and limitations of all projects in the inventory.

Candidates for removal from the list of PSAs

The inventory of projects was scrutinized to identify candidates to be dropped from the list of 48 PSAs on grounds that their goals have been attained. Criteria used to select candidates were basic: a) the PSA description had to be specific enough to permit a decision; b) the PSA had to have at least one project assigned to it; and c) PIs and PSP staff had to confirm that goals had been attained. No PSAs qualified by these criteria (only 4 passed the first two criteria). This was not because of a lack of scientific progress, but rather because most PSAs are not specific enough to support a decision.

The Science Panel's 7 'orphan' PSAs

When the original list of PSAs was finalized in 2011, the Science Panel undertook to promote implementation of seven that the Panel considered otherwise unlikely to gain support (Table 3). This section reports the status of these PSAs.

All were awarded projects and funding (a total of 15 projects, five of which are completed), but in widely differing amounts. Five of the seven PSAs were addressed by projects designed specifically to meet the stated need (PSAs 41, 42, 43, 45, and 46). For example, the ongoing 'Pressures Assessment' (Project 159) directly addresses the need stated in PSA 42 to conduct integrated risk assessments of the principal pressures on Puget Sound. Results are expected to objectively inform and facilitate selection of recovery targets and actions. Depending on outcomes, further assessment may be warranted, for example, of interactions among pressures, and of the spatial and temporal co-incidence of stressors and ecosystem endpoints. Projects 173-175 directly address the need to assess ecosystem services (PSA 45). Development of human wellbeing indicators (PSA 46) is in advanced state of completion at the watershed scale for Hood Canal, and has begun in the Puyallup and Whatcom watersheds (results expected in June 2014). Plans for proceeding with 1-2 workshops to select basin-wide human wellbeing indicators for the vital signs are expected by September 2014, with completion by December 2014.

These provide some of the better examples of how a stated science need can be directly addressed by research (for example, projects 159, 160, 176). This is largely because for these PSAs the objectives are more specifically stated, and it is clearer how results of projects attending to these needs are expected to advance recovery.

Table 3. A list of the 7 'orphan' PSAs that the Science Panel adopted to ensure they would be attended, with a summary of total funds awarded, the number of associated projects, and project numbers (see Appendix C1 and C2 for project descriptions).

PSA No.	Priority Science Action title	Total Budget (corrected)	No. of Projects	Project No. & Status (green = completed, red = ongoing)					
2	Use social science to guide development of adaptive management structures that can effectively link [freshwater and terrestrial] restoration science to management decision-making.	$872,607	2	P10	P11				
41	Conduct institutional analyses of the overall governance and management structures in which Puget Sound recovery strategies operate.	$70,613	2	P157	P158				
42	Conduct integrated risk assessments of the impacts of different pressures on the Puget Sound ecosystem.	$200,000	1	P159					
43	Develop a systematic, transparent, and ecologically-based prioritization tool for near-term actions in the Action Agenda that will support evolutionary learning and adaptation.	$242,116	1	P160					
45	Develop assessments of ecosystem services to help decision makers make informed decisions about restoration and protection.	$1,383,763	6	P170	P171	P172	P173	P174	P175
46	Develop socioeconomic indicators to help measure and report on the human dimensions in ecosystem recovery.	$70,000	2	P176	P177				
48	Evaluate the most effective combinations of regulatory, incentive, and educational programs for different demographics in Puget Sound.	$37,500	1	P179					
	TOTAL	**$2,876,599**	**15**						

Using the inventory of projects

The inventory of projects was used to answer a series of questions intended to illustrate its utility:

1. *How many projects address recovery issues at the level of the entire Puget Sound ecosystem?*

Projects in the inventory address issues at different spatial scales, from local (e.g. the Nisqually delta; P58), to watershed or county (P6), to the entire Puget Sound ecosystem. Ultimate recovery goals encompass the Puget Sound ecosystem, but it is neither necessary nor appropriate that all research projects cover the entire region. Spatial scope of research projects must often be reduced for practical reasons (among others). However, scaling up results or actions from a spatially limited project often exposes additional uncertainties. An answer to the question posed above should provide an expectation of the scope of science-informed recovery interventions and actions that are likely to be pre-adapted for application at the level of the entire ecosystem.

Inclusive assignment criteria were used: a project was considered 'Sound-wide' if its stated scope, targets, sampling locations, and / or results respectively encompassed, were distributed over, or could be applied to the entire ecosystem. For example, one study will "identify floodplain areas in Puget Sound that have the highest potential to advance multiple benefits such as habitat and flood protection". This study qualified as 'Sound-wide' because its description implied that all candidate floodplains will be screened.

The answer was surprisingly large: nearly half (48%) of the 181 projects qualified by these criteria (qualifying project numbers are listed in Table 4). Collectively, they evoke a rich and expansive body of knowledge with potential to inform actions that are scaled to recovery at the ecosystem level.

Table 4. Projects in the inventory that qualify by the stated descriptors.

Descriptor	Total number of projects	Project Numbers
Puget Sound-wide projects	86	P1, P2, P4, P8, P11, P13, P17, P24, P26, P29, P30, P31, P45, P47, P48, P51, P56, P57, P59, P63, P64, P69, P70, P72, P73, P74, P75, P76, P77, P80, P81, P82, P83, P84, P85, P86, P87, P88, P89, P90, P91, P92, P95, P96, P97, P98, P99, P100, P101, P103, P104, P108, P109, P111, P112, P113, P115, P119, P126, P130, P131, P133, P134, P144, P145, P147, P149, P152, P153, P156, P157, P158, P159, P160, P161, P162, P163, P165, P166, P167, P169, P173, P174, P175, P178, P181
Projects with models	30	P3, P7, P11, P34, P36, P37, P39, P40, P42, P43, P44, P48, P52, P53, P54, P55, P59, P73, P74, P84, P89, P92, P94, P97, P104, P119, P131, P146, P149, P156,
Puget Sound-wide models	14	P11, P48, P59, P73, P74, P84, P89, P92, P97, P104, P119, P131, P149, P156
Nearshore	16	P11, P14, P25, P46, P47, P51, P54, P57, P59, P62, P66, P75, P76, P95, P108, P157
Hood Canal	10	P5, P25, P66, P129, P132, P137, P138, P166, P170, P176

2. *What proportion of projects use, are based on, and / or are intended to create models?*

Williams et al. (2009) designed a decision support key to indicate when adaptive management is the most appropriate approach to decision-making for ecosystem restoration. Of 10 steps in the key, step 5 stipulated that adaptive management cannot proceed without predictions generated by models. The question in this part addresses the prevalence of modeling among Puget Sound research projects, with implications for the potential for adaptive management in recovery programs.

Again, inclusive criteria were applied: any type of model (conceptual, simulation, systems, etc.) qualified a project for this category.

The answer was 30 (or 17%; Table 4). This figure is probably conservative in that models might not have been mentioned in the descriptions of some projects that use models. Conversely, it probably over-estimates the number of models that actually support management actions or decision-making (given that the process of applying an academic model incurs several further steps). The result nonetheless suggests that the potential to advance model-based adaptive management and decision making may be higher than generally assumed.

3. *What proportion of projects use, are based on, and / or are intended to create a model that operates at the level of the entire ecosystem?*

This question was answered simply by counting projects that featured in both parts 1 and 2 above. The result was 14, or 8% of the total (Table 4). Given that this figure does not include all Puget Sound-level models, there is great potential to integrate models or model outputs to address novel questions in the service of recovery at the ecosystem level (depending on model compatibility, available data, etc.).

In further examples, the inventory was queried (searched, sorted or filtered) to yield the tally of projects focusing on issues relating to nearshore environments, and to Hood Canal (Table 4). It is intended that the inventory be used in this way to summarize knowledge, integrate strategies and actions, identify collaborators and groups of scientists working on related themes, and find potential funding sources.

Conclusions

If, as envisaged above, PSAs were represented by 48 sectors on a dartboard, the most obvious conclusion to draw from the observed pattern of darts (projects) in the dartboard is that few missed the board entirely. Before concluding that recent and ongoing recovery science in Puget Sound does address stated recovery priorities, however, two caveats warrant repetition. The first is that most PSAs are relatively nonspecific, and the criteria used in assigning projects to PSAs were broad and subjective (the dartboard is large and could hardly be missed). Second, we should ask: *to what extent were the darts thrown first, and the dartboard designed around them?* In other words, to what extent were research priorities defined by projects? The most probable answer is: *to a limited – but inevitable – extent*. Although many of the projects featured in the inventory did not start until after PSAs were selected, their conception began before the 2011-13 BSWP was published. It is likely that some, perhaps many, projects were conceived by members of the recovery science community whose opinions also contributed to consensus about recovery science priorities. Some predetermination of this nature is unavoidable when the best available approach to prioritizing recovery science depends on consensus among experts working in the same ecosystem. It does not mean that research priorities were defined by ongoing projects, or that PSAs are in fact not priorities – far from it: PSAs were derived by consensus, and justified as 'decision-critical'. Thus, a key lesson to draw from this survey is that ongoing recovery science does broadly address Puget Sound recovery priorities *as they are stated in the 2011-13 BSWP*.

A second lesson is that the number and diversity of ongoing and recently completed research projects relating to recovery are large (>181), and in terms of spatial scope, almost half of them encompass the entire ecosystem (as opposed to only a part of it). It is recommended that a process for updating the inventory of recovery research projects be developed (as opposed to recreating it anew every biennium), using a dedicated online database. Funding agencies should then require grantees to enter project data into the database as they are awarded.

A third lesson is that all PSAs received funds, or research attention of some kind, or both.

A fourth lesson, however, is that, because PSAs generally lacked criteria by which to judge when they have been attained, it is difficult to evaluate progress, or determine when a PSA can be removed from the list. Consequences are that, as currently written, few if any PSAs are candidates for removal. Accordingly, the list of PSAs can easily grow, but cannot shrink. A pressing need is for Priority Science Actions and their goals to be made sufficiently specific to permit assessments of progress. This should include requirements for projects relating to goals and assessment of progress to be described in RFPs for recovery science, matched by more exacting reporting obligations for grantees to describe how their results should be applied. Wherever appropriate, scientists conducting recovery research should be actively involved in the process of transforming research results to actions.

A fifth lesson relates to total expenditure on recovery science. This may be the first time such an estimate has been attempted. A few respondents expressed surprise at a total in excess of $50 million, but in opposing ways: some were surprised by how large it is, others by how small. Additional perspective is needed to put this figure in context. The total was derived from projects spread over a number of years. If we assume that interval to be seven years between 2009 and 2016, estimated expenditure on science *per year* is about $7 million. This figure seems modest, especially when further considered in context of:

- the vast size and complexity of the ecosystem;
- the long duration of its decline (> 100 years), compared to the proximity of the recovery deadline (2020);
- the large amount expended over that period which contributed, directly or indirectly, to its decline, compared to the amount expended so far on its recovery;
- the fact that humans – the principal source of stresses to the ecosystem – are already numerous, and are projected to continue to increase in the region for the foreseeable future;
- the current status of the ecosystem, compared to its targeted status;
- the high proportion of what is currently unknown that must be learned to achieve recovery;
- the fact that recovery efforts to date have had little detectable effect on most indicators of ecosystem status (Puget Sound Partnership 2013).

Absolute cost of recovery is of abiding concern, but systematic assessment of cost *effectiveness* rarely features in our approach to recovery. Since ecosystem recovery is an expensive process largely underwritten by public funds, relative costs and benefits should feature in planning and implementation of recovery strategies and projects.

Finally, the imagined impact of at least 181 research projects focusing on such a diverse array of recovery priorities engenders hope that recovery gains will be forthcoming. However, it also generates expectation, justified or not, that we will have a clearer vision of how recovery should proceed, and a better understanding of why recovery progress has been slower than expected. The fact that we currently have neither amplifies the need for advances in discovery that arise from research to be more directly and efficiently applied to the recovery of Puget Sound. Suggestions for how to more directly apply science to recovery are described in Part IV.

Part II: Studies Recommended by Recovery Scientists and Practitioners

This section describes recommendations from recovery scientists and practitioners for research priorities relating to Puget Sound recovery.

A total of 265 scientists and recovery practitioners were invited to recommend research priorities relating to Puget Sound recovery (see Approaches and Methods, above). Only 18 (6.8%) responded, with a total of 87 recommendations. These are listed in Appendix E under the same Action Agenda strategy and sub-strategy headings that were used in Appendix C. All submitted responses were informative, and some were constructively critical. One respondent accompanied insightful recommendations with a comment about the list of PSAs: “there are very few real research priorities on that old list (some exceptions are PSAs 16, 19, and 20, all of which still apply)”. Several respondents remarked that PSAs on the list varied greatly in degree of specificity, or were not sufficiently specific, while others noted redundancies (see the General Commentary column in Appendix E). Few recommended removal of PSAs, but none provided sufficient justification for removal.

Comparison between 2011-13 and 2014-16 BSWPs

Proportions of recommendations within each Action Agenda sub-strategy from the 2011-13 and 2014-16 Biennial Science Work Plans are compared in Table 5. As presented, the lists are positively but not significantly correlated with each other ($r=0.41$, $df=17$, $P<0.1$). However, if recommendations within the marine and nearshore strategy relating to habitats are combined with those relating to marine and nearshore species and food webs, the proportions become highly correlated ($r=0.9$, $df=16$, $P<<0.001$). Rationale for combining the two categories is that subjective assignments of recommendations to sub-strategies may not have been consistent from one BSWP to the next, and that this may apply more to marine and nearshore projects than to others. For example, eelgrass, which features frequently among marine and nearshore projects, is both a species *and* a habitat and can be classified as either. Correspondence between the two lists is of interest because, all else being equal, a correlation would result if on both occasions responses represented a random sample from the community of recovery scientists. The correlation may simply reflect the (testable) possibility that among different disciplines within Puget Sound’s recovery science community, the largest group focuses on marine and nearshore issues, and their numbers have not changed much in the last 2 years. The implication is that this method of generating recovery science priorities may better reflect the make-up of the recovery science community than priorities for research.

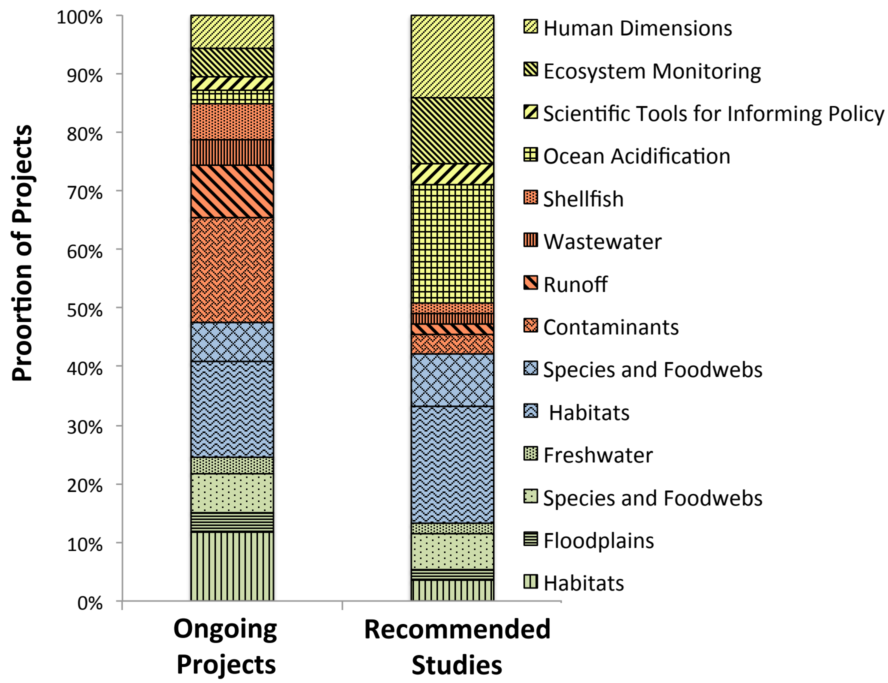
Table 5. Comparison of recommended science priorities within each Action Agenda Sub-

Action Agenda Strategy	Action Agenda Sub-strategy	Percent of recommendations in each category	
		2011-13 BSWP	2014-16 BSWP
Upland, Terrestrial & Freshwater	Habitats	7.9	6.9
	Species & Food Webs	4.6	8.0
	Mitigation	2.6	1.1
Marine & Nearshore	Habitats	6.6	26.4
	Species & Food Webs	23.7	11.5
	Mitigation	5.3	0.0
Pollution	Toxics	9.9	4.6
	Runoff from the Environment	6.6	2.3
	Wastewater	2.0	2.3
	Shellfish	0.7	2.3
	Oil Spills	0.0	0.0
	Other	0.7	0.0
Climate Change / OA		4.6	4.6
Human Dimensions		5.3	10.3
Sustaining, Coordinating, & Using Science to Adapt Actions	Building Capacity	2.6	0.0
	Foundational Questions	5.9	0.0
	Scientific Tools for Informing Policy	3.3	4.6
	Integrated, Sustained Monitoring	5.9	14.9
	Education, Training & Outreach	2.0	0.0
	Total Number of Recommendations	152	87

Comparing ongoing with recommended projects in the 2014-16 BSWP

For the 2014-16 BSWP, recommendations were received for all Action Agenda sub-strategies that also featured in the inventory of projects. Climate change received the minimum number of recommendations (1), and marine and nearshore habitats received the maximum (23; Appendix E). Proportions of projects within Action Agenda sub-strategies of ongoing and recently complete research differed from those within recommended studies, especially when recommendations from reports were included (Figure 4). Within ongoing and recently completed research, most projects addressed issues relating to pollution and contaminants (red), while relatively few address 'Other' issues relating to ocean acidification, scientific tools, ecosystem monitoring and human dimensions (yellow). This pattern was reversed among recommended studies: sub-strategies for ocean acidification, ecosystem monitoring, and social sciences are expanded, whereas those for toxics and pollutants are diminished. In addition, a greater proportion of projects focused on Marine and Nearshore issues among recommended studies than among ongoing projects (Figure 4). These differences may reflect changing emphases in research relating to recovery, in particular, the addition of ocean acidification as a major category, and re-emphasis on social sciences.

Figure 4. Proportion of projects assigned to sub-strategies of the Action Agenda in the inventory of ongoing and recently completed projects (left, from Appendix C) and in the inventory of recommended studies (right; from Appendix E). Action Agenda strategy areas are color coded as Terrestrial and Freshwater (green), Marine and Nearshore (blue), Pollutants and Toxics (red), and Other (yellow).



Prevalent themes among studies recommended by respondents

The sample size of recommendations from individuals (Appendix E) was too small to draw conclusions about priorities by consensus. However, research themes in the inventory that were recommended by more than one respondent are described below.

1. *How are beach formation processes affected by human actions, especially armoring?*

Beaches are dynamic features of the land-sea margin, morphed by the balance of erosion and sediment deposition processes operating at multiple scales. A total of 17 recommendations (R16-R32) from 5 respondents urged better understanding of beach formation processes, sediment budgets, and their interactions with ecological communities, such that effects of natural processes and human actions (e.g. armoring) can be distinguished.

2. *Human impacts on eelgrass*

Two respondents made 5 recommendations (R34-R38) for research on a diversity of themes relating to eelgrass: effects of climate change, ocean acidification, and increased CO_2; effects on donor eelgrass populations of harvesting for transplantation; effects of shoreline development, nitrogen supplementation, and algal blooms on eelgrass.

3. *Basic understanding of marine food webs*

Three respondents made 10 recommendations (R40-R49) for research on marine food webs. These were largely intended to improve basic understanding of how food web dynamics vary spatially across the Sound, how recovery strategies targeting linked species in the food web are likely to conflict with each other, and the factors that limit forage fish populations.

4. *Relationships between human inputs of nitrogen, dissolved oxygen, and harmful algal blooms.*

Four respondents made 4 recommendations (R56-R59) for research relating to effects of human inputs of nitrogen to Puget Sound on dissolved oxygen and harmful algal blooms, and how ocean acidification might change these relationships. Better understanding is needed about the triggers of harmful algal blooms and their threats to human health, with focus on communicating the risks associated with HABs among Tribal people.

Overall, one third of all recommendations targeted uncertainties relating to marine, nearshore, and shoreline processes.

Conclusions

Possible reasons for such a low response rate to requests for recovery research recommendations include insufficient incentive to respond, given competing demands for time. A related possibility is lack of confidence in this process for prioritizing recovery science. Another is that it is less than 3 years since scientists were polled about recovery priorities for the 2011-13 BSWP, and perceptions may not have changed enough to motivate a response. A consequence is that the sample size of recommendations from individuals was too small draw conclusions about priorities based on consensus. An alternative approach to listing decision-critical science is outlined below in Part IV.

We encourage prospective sponsors of recovery science in Puget Sound to view the recommendations presented above as relevant and timely research topics that have some interest from the scientific community but that have not been discussed or vetted in any consensus process.

Part III: Studies Recommended in Recent Reports

In this section, the Science Panel presents recommendations from reports prepared in the last biennium that address some of the key topics highlighted by the Panel in the 2011-13 BSWP. These recommendations complement the research recommendations made by individuals that are summarized in Part II (and Appendix E). The Science Panel views recommendations in the following reports as candidates for research priorities for the next biennium: the Blue Ribbon Panel's report on Ocean Acidification (2012), a report on Ecosystem-based Management of Forage Fish in Puget Sound (Francis, 2013), the strategic plan of the Salish Sea Marine Survival Project, a report of a workshop to identify research gaps in the social sciences (Biedenweg and Nelson 2013), and a list of monitoring gaps drawn up by work groups of the Puget Sound Ecosystem Monitoring Program.

These reports reflect diversity in the formality of the process by which recommendations were made, the degree of consensus achieved in their definition, and whether or not the process was documented. For example, recommendations from the report on ocean acidification were the product of a formally documented process instigated by the Governor, with input from and consensus by many experts. By contrast, recommendations about social science needs were generated during a one-day workshop that applied the world café method of small to large group discussions. While there may be no difference in intrinsic validity between recommendations from these different sources, they do differ in degree of validation, at least at face value. Accordingly, recommendations are presented below in order of apparent degree of validation.

We recognize that any prioritization process that the Science Panel might use would not align with the decision situations that others face when selecting areas of strategic focus or investment in scientific investigation. Therefore, we encourage prospective sponsors of recovery science in Puget Sound to view the recommendations presented below as relevant and timely research, some better validated than others, but all backed by the credibility of scientists currently working on ecosystem recovery in Puget Sound. The presentations below have not been standardized but rather are presented in a way that reflects the manner in which the recommendations are presented in the subject reports.

Ocean acidification

"Between 2005 and 2009, disastrous production failures at Pacific Northwest oyster hatcheries signaled a shift in ocean chemistry that has profound implications for Washington's marine environment. Billions of oyster larvae were dying at the hatcheries, which raise young oysters in seawater. Research soon revealed the cause: the arrival of low-pH seawater along the West Coast, which created conditions corrosive to shell-forming organisms like young oysters. The problem, in short, was ocean acidification" (quoted from Washington State Blue Ribbon Panel on Ocean Acidification, 2012; for a technical summary of ocean acidification in Washington, see Feely et al., 2012).

"Recognizing the risks of ocean acidification to Washington, Governor Christine Gregoire created the Washington State Blue Ribbon Panel on Ocean Acidification to chart a course for addressing the causes and consequences of acidification. The Panel, convened in February 2012, was assembled under the auspices of the Washington Shellfish Initiative, a regional partnership established to implement the National Oceanic and Atmospheric Administration's (NOAA)

National Shellfish Initiative. Members included scientists; public opinion leaders; industry representatives; state, local, federal, and tribal policymakers; and conservation community representatives.

The Governor charged the Panel to:

- Review and summarize the current state of scientific knowledge of ocean acidification,
- Identify the research and monitoring needed to increase scientific understanding and improve resource management,
- Develop recommendations to respond to ocean acidification and reduce its harmful causes and effects, and
- Identify opportunities to improve coordination and partnerships and to enhance public awareness and understanding of ocean acidification and how to address it."

A recommendation of the Blue Ribbon Panel on Ocean Acidification was to create the Washington Ocean Acidification Center, which was established in July 2013 under direction from the Washington State Legislature and Governor Inslee. The Center is led by the College of the Environment at the University of Washington and includes faculty and staff from multiple departments and disciplines. It is modeled after and integrated with the UW's Climate Impacts Group, a leader in developing and delivering decision-relevant science. The Center is co-directed by Jan Newton (Applied Physics Laboratory, Oceanography) and Terrie Klinger (Marine and Environmental Affairs). The Center is charged by the legislature to execute five priority actions:

- Ensure continued **water quality monitoring at the six existing shellfish hatcheries** and rearing areas to enable real-time management of hatcheries under changing pH conditions. The monitoring data have enabled hatchery operators to avoid drawing acidic water into the hatcheries and rearing areas.
- Establish an **expanded and sustained ocean acidification monitoring network** to measure trends in local acidification conditions and related biological responses. This monitoring will allow detection of local acidification conditions and increase our scientific understanding of local species responses.
- Establish the **ability to make short-term forecasts of corrosive conditions** for application to shellfish hatcheries, growing areas, and other areas of concern. A real-time online tool will be developed and accessible to shellfish growers and managers to track acidification on a scale of days to weeks, giving them time to change or adjust their hatcheries' operation.
- Conduct **laboratory studies** to assess the direct causes and effects of ocean acidification, alone and in combination with other stressors, on Washington's species and ecosystems. The studies will focus on determining the biological responses of species of ecological, economic, and cultural significance, to a full suite of stressors to which they are exposed, and will help estimate the genetic potential of these species to adapt to ocean acidification.
- Investigate and develop **commercial-scale water treatment methods** or hatchery designs to protect larvae from corrosive seawater. Scientists from the UW will help shellfish growers assess the effectiveness of the adaptation measures.

The Center will achieve these goals and others by:

- Bringing a regional focus to research priorities and serving as a regional hub for research endeavors.
- Training the next generation of scientists, managers, and decision-makers to face the challenges posed by ocean acidification.
- Using a distributed network model of organization to join the expertise of UW scientists with that of other regional academic institutions, agencies, and organizations.
- Engaging with industry representatives, state, local, federal, and tribal policy makers, and public opinion makers through specific activities and through the formation of an advisory board and a science advisory team, both of which will be used to help guide the activities of the Center.

The WOAC will participate in the implementation and / or management of actions recommended by the Blue Ribbon Panel that were summarized in Washington State Blue Ribbon Panel on Ocean Acidification report of 2012. Actions requiring or relating to science are listed in Table 6, with commentary from WOAC's director (Jan Newton) about funding, priorities, partners, and relevance to this BSWP.

Ocean Acidification is a new addition to the list of issues relating to the health and recovery of Puget Sound, with its own priorities for research that will compete with others for limited available funds. Funds for OA research may derive from a mix of Federal (NOAA & EPA, possibly USGS), State (LOs, Legislature to WOAC), tribes, foundations, and others. Newton notes that a new Vital Sign for OA is needed, based on the saturation state of aragonite in Puget Sound, as others have adopted (e.g., California Current Acidification Network, C-CAN, developed by Sea Grant, Moore Foundation, NOAA, US IOOS, scientists, growers, and other industry reps; also the Global Ocean Acidification Observing Network, GOA-ON, spearheaded by NOAA and UK OA Program through two workshops with ~100 scientists from ~30 countries). Development of the Vital Sign will be based on results of Action 7.1.1 in Table 6.

Recommended priorities for research on OA in the coming biennium are highlighted in green in Table 6.

Table 6. Research recommendations from the Washington State Blue Ribbon Panel's report on Ocean Acidification (2012). Actions that have been funded by State Legislature for implementation by WOAC are in blue; recommendations for inclusions in the 2014-16 the BSWP are in green.

Action No.	Action Title	Commentary
Action 4.1.3	Analyze data to determine if there is a causal relationship between local air emissions and local marine water acidity. If the data confirms such a relationship, take actions to reduce local air emissions that contribute to acidification.	NOAA PMEL is conducting this data review and assessment. Results should be available within the biennium.Contact Dick Feely and Simone Alin, NOAA PMEL.
Action 6.1.1	Develop vegetation-based systems of remediation for use in upland habitats and in shellfish areas. [KEA]	This action is not funded. A pending proposal to the Allen Family Foundation (Joth Davis et al.) will begin this work if funded.
Action 6.2.1	Ensure continued water quality monitoring at the six existing shellfish hatcheries and rearing areas to enable real-time management of hatcheries under changing pH conditions. [KEA]	This action is being implemented by PCSGA (Pacific Coast Shellfish Growers Association) with support from state funds administered through WOAC. Contact: Jan Newton, WOAC.
Action 6.2.2	Expand the deployment of instruments and chemical monitoring to post-hatchery shellfish facilities and farms.	Support from NANOOS through US IOOS (United States Integrated Ocean Observing System, NOAA) are partially funding this work, but the action is not fully funded. Also see Action 7.1.3 award to NANOOS. Contact Jan Newton, NANOOS, and Bill Dewey, PCSGA
Action 6.2.3	Investigate and develop commercial-scale water treatment methods or hatchery designs to protect larvae from corrosive seawater. [KEA]	This action is being implemented by PCSGA (Pacific Coast Shellfish Growers Association) with support from state funds administered through WOAC. Contact: Jan Newton, WOAC.
Action 6.2.4	Develop and incorporate acidification indicators and thresholds to guide adaptive action for species and places.	This work will be informed by actions 7.1.1, 6.2.1, 7.4.1 and 6.2.3. It merits funding in the next bienium.
Action 6.3.5	Investigate genetic mechanisms and selective breeding approaches for acidification tolerance in shellfish and other vulnerable marine species.	This work is not funded at this time.
Action 7.1.1	Establish an expanded and sustained ocean acidification monitoring network to measure trends in local acidification conditions and related biological responses. [KEA]	This action is being implemented by a consortium of state, federal and other partners with funds administered through WOAC. Contact: Jan Newton/Terrie Klinger, WOAC.
Action 7.1.2	Develop predictive relationships for indicators of ocean acidification (pH and aragonite saturation state).	NOAA PMEL is performing this data review and assessment, beginning with coastal waters and following with an assement for Puget Sound waters. Contact Dick Feely and Simone Alin, NOAA PMEL.
Action 7.1.3	Support development of new technologies for monitoring ocean acidification.	WOAC, NOAA PMEL and others partners are engaged in two acitivities that address this action. 1) The Wendy Schmidt X-PRIZE aims to spur development of new sensor technologies. WOAC and NOAA PMEL will be involved with the demonstrations at Seattle Aquarium and other venues. 2) NOAA IOOS and OAP (Ocean Acidification Program) released an FFO for marine sensor innovation for funding in FY 14 and FY15. NANOOS is involved with 5 proposals, with NOAA PMEL a partner on 4 of these. One proposal, to work with shellfish growers in testing a new, less expensive sensor for pCO_2 and pH (thus aragonite saturation), was selected for funding in FY14 for 3 years, involving both NANOOS and NOAA PMEL.
Action 7.2.1	Quantify key natural and human-influenced processes that contribute to acidification based on estimates of sources, sinks, and transfer rates for carbon and nitrogen. [KEA]	The EPA has provided funding to the Washington Department of Ecology to perform this analysis. Additional related work could be performed through WOAC depending on future funding. Contact: Mindy Roberts & Hedia Adlesman, Ecology.
Action 7.2.2	Develop new models or refine existing models to include biogeochemical processes of importance to ocean acidification.	NOAA NWFSC is building ecological models that might be coupled with physical models to address this action once Actions 7.4.1 and 7.2.1 are complete. Likely be implemented in the next biennium. Potential contact: John Stein, NOAA NWFSC.
Action 7.3.1	Determine the association between water and sediment chemistry and shellfish production in hatcheries and in the natural environment. [KEA]	WA DNR is performing field studies in the natural environment. Conact: Cinde Donohue, WA DNR.
Action 7.3.2	Conduct laboratory studies to assess the direct effects of ocean acidification, alone and in combination with other stressors, on local species and ecosystems. [KEA]	This action is being implemented by a team of researchers from UW, WWU, and NOAA NWFSC with state funds administered through WOAC. Experiments will be performed on copepods, krill, crab, oysters and geoduck. Contact: Newton/Klinger WOAC; Julie Keister PI
Action 7.3.3	Conduct field studies to characterize the effects of ocean acidification, alone and in combination with other stressors, on local species.	This action is not funded.
Action 7.4.1	Establish the ability to make short-term forecasts of corrosive conditions for application to shellfish hatcheries, growing areas, and other areas of concern. [KEA]	This action is being implemented by a team from UW with state funds adminstered through WOAC. The model will address the outer coast, Puget Sound and Columbia River. Contact: Newton/Klinger, WOAC. Parker MacCready, PI
Action 7.4.2	Enhance the ability to predict the long-term future status of carbon chemistry and pH in Washington's waters and create models to project ecological responses to predicted ocean acidification conditions.	This action is likely best implemented in a future biennium.
Action 7.4.3	Enhance the ability to model the response of organisms and populations to ocean acidification to improve our understanding of biological responses.	This action is likely best implemented in a future biennium.
Action 9.1.2	Create an ocean acidification science coordination team to promote scientific collaboration across agencies and organiza- tions and connect ocean acidification science to adaptation and policy needs.	This action is being implemented by WOAC with state fund. Contact: Newton/Klinger, WOAC.

Ecosystem-based management of forage fish in Puget Sound

In the Spring of 2013, the Puget Sound Institute convened a 9-member study panel ("the Study Panel") to assess the state of the science, and to recommend and conduct data analyses related to ecosystem-based management of forage fish in Puget Sound. Members of this panel include forage fish experts from across the West Coast from universities and state and federal (including Canadian) government agencies. In August 2013, the Study Panel met for its first workshop. A day of presentations by and discussions with other regional scientists and stakeholders, followed by 3 days of discussions internal to the Study Panel, resulted in this summary and proposed research plan.

The Study Panel agreed upon several facts with respect to Puget Sound forage fish and, specifically, Pacific herring (a Puget Sound Partnership Vital Sign):

1. Spawn deposition surveys are sufficient for estimating herring adult spawner biomass, and for describing trends in adult spawner biomass through time. However, the assumptions contained in the model that converts egg density estimates to adult biomass should be re-evaluated. The spawn deposition surveys and acoustic/trawl surveys (conducted before 2009) estimate the same abundance trends overall.
2. The major herring spawning locations are known.
3. Herring and sand lance are key prey items in the diets of several Puget Sound predators, including fish, birds and mammal.

However, several key gaps exist in our understanding of Puget Sound forage fish, preventing effective management. The Study Panel's work plan was developed to address these gaps, which include:

1. Status of/trends in abundance of forage fish species other than herring;
2. Key vulnerabilities of forage fish;
3. Abundance/biomass of forage fish needed to support key ecosystem predators;
4. Prey base/food supply for forage fish;
5. Consequences of herring age truncation;
6. Partial migration by herring out of Puget Sound.

The Study Panel recommended *analyses that are of key importance to the recovery of Pacific herring*, and achieving recovery targets established by the Puget Sound Partnership:

1. Identify key vulnerabilities of herring to determine what limits their populations.
2. Determine how much herring biomass – of what size, and where – is needed to sustain top predators.
3. Develop a life-cycle model for use in determining how the most likely stressors affect herring populations.
4. Build a management strategy evaluation to test the effects of individual, or suites of, management actions on key stressors to herring, based upon identified key vulnerabilities and using a life-cycle model.

Several key gaps in information cannot be filled by a study panel, but rather ***require ongoing monitoring***. The Study Panel also made recommendations for monitoring actions that are necessary for ecosystem-based management of forage fish in Puget Sound. These include:

5. Collect biological samples to establish age/size composition (including of herring, to support the Vital Sign Indicator/Target).
6. Conduct ichthyoplankton surveys, to provide information about early life stages, and especially for estimating abundance of sand lance.
7. Conduct zooplankton surveys, to provide information about prey base for forage fish.

A list of research priorities for ecosystem-based management of forage fish

1. Identify key stressors to forage fish and effective management actions to protect them

Action 1.1: Build life-cycle model for forage fish (Proposed Work Plan Project 7)
Estimated cost: $20,000

Action 1.2: Identify critical stressors for forage fish, *using above life-cycle model* (Proposed Work Plan Project 7)
Estimated cost: $75,000

Action 1.3: Management Strategy Evaluation: Construct operating model to determine the effects of different management actions to limit key stressors, given their effects at different life stages, *using above life-cycle model and identified critical stressors* (Proposed Work Plan Project 1)
Estimated cost: $110,000

2. Determine abundance of (non-herring) forage fish

Action 2.1: Estimate forage fish abundance using predator diets (Proposed Work Plan Project 8)
Estimated cost: $34,000

Action 2.2: Estimate forage fish abundance using seabird behavior (Proposed Work Plan Project 10)
Estimated cost: $20,000

3. Determine biomass needed to support key predators (Proposed Work Plan Project 2)
Action 3.1: Estimate predator needs in space and time
Estimated cost: $68,000

The Salish Sea marine survival project

Over the past 15 years, several hundred million dollars have been spent on habitat recovery in Puget Sound. Salmonid harvest rates have been reduced significantly, and hatchery management has undergone major changes to improve the fitness of wild and hatchery populations. However, the abundance of steelhead, Chinook, and coho salmon remains well below what it was 30 years ago.

Changes in the Salish Sea are thought to be significantly affecting the abundance of our region's salmon and steelhead, as evidenced by:

1. Chinook, coho and steelhead survival in the marine environment—from juvenile smolts to returning adults--has declined by up to tenfold since the 1980s. The survival of coastal and Columbia River populations has varied since the 1980's but does not follow the same overall declining trend.[1]
2. 80% of juvenile steelhead die in Puget Sound on their way to the Pacific Ocean.[2]
3. The early marine phase, as juveniles in the Salish Sea, is generally considered one of the most critical periods for salmon and steelhead, where they are known to experience some of their most rapid growth and highest mortality rates.
4. Data suggesting that the Salish Sea ecosystem has changed dramatically over the past 30 years includes increased water temperatures, increased acidity, the demise of the Fraser River eulachon and cherry point herring populations, less kelp and eel grass, more pink salmon, more harmful algae, more jellyfish and noctiluca (food web 'junk food'), more harbor seals and porpoises.

Interactions between salmon life cycles and changes in the Salish Sea are complex. While factors affecting salmon survival in freshwater are well understood, our collective understanding about salmon survival in the marine environment is limited. The Salish Sea Marine Survival Project will determine the most significant factors affecting juvenile salmon survival in the Salish Sea. This directly addresses PSA 9 from the 2011-13 BSWP: *Why are juvenile Chinook, coho, and steelhead dying in the Salish Sea marine environment at unexpectedly high rates?* Thirty seven entities, encompassing much of the region's fisheries and marine ecosystem research and management complex, are now working together to answer this question. Addressing factors that affect survival and driving real, lasting recovery of the species will require a much more detailed and complete understanding of how salmon and steelhead interact with the physical, chemical and biological characteristics of the Salish Sea.

Overall Project Cost:

- $20 million dollars (<u>new money</u>) over $5 years: $10 million U.S / $10 million Canada
- Raised approximately $12 million to date: $4 million U.S. / $8 million Canada
- Anchored by $5 million grant from the Pacific Salmon Commission Southern Endowment Fund, split 50/50 between US and Canada, and $788,000 from Washington State via the Puget Sound Partnership
- Need $6 million in U.S. / $2 million in Canada

The Salish Sea Marine Survival Project is a five-year international research effort that leverages human and financial resources from the United States and Canada to determine the most significant factors affecting the survival of juvenile salmon and steelhead in the Salish Sea marine environment. It addresses a key uncertainty impeding salmon recovery and sustainable fisheries in the shared

[1] Decline of Salmon and Steelhead Marine Survival in the Salish Sea. *http://www.lltk.org/rebuildingpopulations/salish-sea-marine-survival/overview.*
[2] Figure 11. Puget Sound Steelhead Marine Survival Workgroup. 2014. Research Work Plan: Marine Survival of Puget Sound Steelhead. Long Live the Kings, Seattle, WA.

waters of British Columbia and Washington State. The effort is coordinated by nonprofits, Long Live the Kings (LLTK) in the U.S./Puget Sound, and the Pacific Salmon Foundation (PSF) in Canada/Strait of Georgia.

Beginning in 2012, LLTK and PSF convened federal, state, tribal and academic scientists from multiple disciplines to develop a comprehensive and highly coordinated ecosystem-based research program. Preliminary recommendations were established for Puget Sound by the U.S. Salish Sea Technical Team (see list of scientists below) and for the Strait of Georgia by a PSF science team. Then, in November 2012, a workshop with 90 participants and a 15 member advisory panel (including experts in the field working in the Gulf of Alaska and Columbia River Plume/California Current) was held to review the recommendations and receive feedback from the broader scientific community regarding the critical elements of a US-Canada research program.

The preliminary research recommendations and workshop results led to formal research planning in 2013. For Puget Sound, a subgroup of the Technical Team worked with others to complete the Puget Sound Steelhead research work plan. The plan focuses on locating specific juvenile steelhead mortality hotspots in Puget Sound and identifying mortality causes ranging from pathogens to predators. And, the U.S. Salish Sea Technical Team provided their initial round of Chinook and coho research recommendations. The research recommendations (Table 7) focus primarily on the first two to three years of the five-year research effort, developing the backbone of the research project, including the data analysis framework and the core bottom-up sampling program that focuses on understanding juvenile salmon growth and their association with the physical and biological (plankton) characteristics that are the cornerstone of the Salish Sea ecosystem. Research planning will continue over the five-year research phase, with the results of this initial work informing next steps.

Research began in 2014. Today, as part of this project, over 150 scientists and technicians from federal, state, tribal, academic, and nonprofit institutions are in the field and in laboratories assessing the condition of juvenile Chinook, coho and steelhead and their marine environment. Field technicians are intensively collecting fish and their prey as the migrate downriver and through estuary and nearshore environments, commercial fishermen and the Canadian Coast Guard have mobilized large vessels to help offshore, acoustic arrays have been installed and are tracking fish movement and survival, gliders and buoys are being deployed to monitor ocean conditions, and new technology for tracking marine mammal encounters with salmon and steelhead is being utilized.

Relevant reference documents are listed below (all are available at *www.marinesurvivalproject.org*).

Pacific Salmon Foundation (Riddell, B., I. Pearsall and Science Panel [R.J. Beamish, B. Devlin, A.P. Farrell, S. McFarlane, K. Miller-Saunders, A. Tautz, A. Trites, and C. Walters]). 2009. Strait of Georgia Chinook and Coho Proposal. November 17, 2009.

U.S. Salish Sea Technical Team. 2012. Hypotheses and Preliminary Research Recommendations for Puget Sound. Long Live the Kings, Seattle, WA.

Schmidt, M., C. Greene, P. Lawson. 2013. The Results and Recommendations of the Salish Sea Marine Survival Research Planning and Ecosystem Indicators Development Workshops – November 5-9, 2012. Long Live the Kings, Seattle, WA.

Puget Sound Steelhead Marine Survival Workgroup. 2014. Research Work Plan: Marine Survival of Puget Sound Steelhead. Long Live the Kings, Seattle, WA.

U.S. Salish Sea Technical Team. 2014 (unpublished/not posted to web site). Puget Sound Marine Survival Research Plan. Long Live the Kings, Seattle, WA.

U.S. Salish Sea Technical Team: In Puget Sound, the Technical Science Team developing and implementing the work includes:		
Alan Chapman	ESA Coordinator	Lummi Nation
Barry Berejikian	Research Fisheries Biologist, Behavioral Ecology Team Leader	NOAA Northwest Fisheries Science Center
Correigh Greene	Research Fish Biologist, Watershed Program	NOAA Northwest Fisheries Science Center
Chris Ellings	Research Biologist and Salmon Recovery Program Coordinator	Nisqually Indian Tribe
Chris Harvey	Fishery Biologist	NOAA Northwest Fisheries Science Center
Dave Beauchamp	Professor, Fish Ecology	University of Washington
	Ecologist	US Geological Survey
Erik Neatherlin	Chief Fisheries Scientist	Washington Department of Fish and Wildlife
Jan Newton	Principal Oceanographer	University of Washington
Josh Chamberlin	Fish Biologist	NOAA Northwest Fisheries Science Center
Julie Keister	Assistant Professor, Biological Oceanographer/Zooplankton Ecologist	University of Washington
Ken Warheit	Molecular Genetics Laboratory Leader	Washington Department of Fish and Wildlife
Mike Crewson	Fisheries Enhancement Scientist	Tulalip Tribes
Neala Kendall	Research Scientist	Washington Department of Fish and Wildlife
Paul Hershberger	Research Fisheries Biologist, Ecology and Disease	US Geological Survey
Sandie O'Neill	Research Fish Biologist	Washington Department of Fish and Wildlife

Table 7. Research recommendations for Puget Sound sector of the Salish Sea Marine Survival Project, including their status and relevance to the BSWP. Shades of green reflect the level of intensity for each activity: light = low, dark = high. Hatching denotes that planning is ongoing. Funding represents actual current + estimated future costs for each activity over their entire time period.

Salish Sea Marine Survival Project - Puget Sound Chinook & Coho Studies w/ focus on 2014-2015	**Timeline, 201-**					**Relevance to BWSP** All should be listed in BWSP, but highest priority recommendations for BWSP due to relevance beyond addressing priority 9 in BWSP are in yellow.	**Status**	**Funded**	**Remaining Cost**	**In Kind**
Trend Analyses & Modeling - *Platform for comprehensive data analyses for the entire project. Combine factors & build out to fundamental survival drivers. Highly integrated U.S. - Canada*	*4*	*5*	*6*	*7*	*8*	*In kind largely WDFW, NOAA, PS Treaty Tribes*		**$700,000**	**$1,355,000**	**$160,000**
A1. Chinook & coho marine survival trends - Evaluate long-term survival trends. Formalize for use in correlative analyses.						list in BWSP. Current Funding = PSC Southern Endowment Fund.	funded - ongoing	$75,000	$85,000	$60,000
A2. Life-history characteristics - Evaluate long-term data sets of life-history characteristics & correlations w/ survival. Model outmigrant life-history.						list in BWSP. Current Funding = Trout Unlimited ($80k), & PSC Southern Endowment Fund ($20k)	partial funding	$100,000	$90,000	$30,000
A3. Ecosystem indicators relative to salmon										
A.3.1. Ecosystem indicators dataset - Establish & manage data, evaluate/model metrics for correlations w/ survival, individually & combined. Inc. past data from A.3.2-5 & new from A5+.						Broad application. Establishes dataset for use beyond salmon (priority 9 in BWSP). Feeds Puget Sound ecosystem modeling & indicators tracking. Current Funding = PSC Southern Endowment Fund	partial funding	$90,000	$400,000	
A.3.2. Zooplantkon time series - process/analyze Puget Sound's only long-term (2003-14) quantiative dataset (JEMS).						list in BWSP. Current Funding = PSC Southern Endowment Fund	funded - ongoing	$30,000		
A.3.2.1 Past/present zooplankton samples - process & evaluate samples prior to survival decline (B. Frost - 1970s) compared to present samples.						Broad application beyond addressing priority 9 in BSWP. Evaluates ecosystem regime shift in Puget Sound.	not funded		$75,000	
A.3.3. WDFW zooplankton dataset - Compile & assess 30 year, qualitative, presence/absence data set.						list in BWSP. Funding = WA Sea Grant	funded - ongoing	$15,000		
A.3.4. Analyze long-term stratification datasets as a proxy for primary production - Correlative analyses & ecosystem modeling improvements.						list in BWSP. Funding = PSC Southern Endowment Fund	funded	$45,000		
A.3.5. Analyze phytoplankton production rates, timing, & variability to assess inter-annual & inter-basin variation - Correlative analyses & ecosystem modeling improvements.						NPZ (well, working nutrient-phytoplankton-microzooplankton-detritus-oxygen-pH model) for PS being established in MoSSea via WOAC (~95k committed). A.3.5 will in part tailor model to respond to bloom timing, & then add in the larger zooplankton component w focus on salmon prey. A3.5 & A4. have broad application, addresses ecosystem modeling needs ID'ed by Science Panel & others. Very relevant & recommended highest priority for BSWP.	in kind funding	$95,000	$105,000	
A4. End-to-end, spatiotemporal ecosystem model for Puget Sound & potentially the greater Salish Sea - Current proposal to establish an Atlantis model for Puget Sound; however, working w/ the Canadians to formalize best approach Salish Sea wide. Early focus is on NPZ component (see A.3.5).							in kind funding		$400,000	$70,000
Next Steps - Continue to combine & analyze information & build back to fundamental survival drivers. Comprehensive analyses & reporting.								$250,000	$200,000	

Salish Sea Marine Survival Project - Puget Sound Chinook & Coho Studies w/ focus on 2014-2015	**Timeline, 201-**					**Relevance to BWSP** All address priority 9 & should be listed in BWSP. Recommended PSEMP priorities in blue.	**Status**	**Funded**	**Remaining Cost**	**In Kind**
***Core Bottom-Up Sampling Program - juvenile** salmon growth & assoc. w/ the physical & biological characteristics, the cornerstone of the Salish Sea ecosystem - Highly integrated U.S. - Canada*	*4*	*5*	*6*	*7*	*8*	*In kind largely PS Treaty Tribes, WDFW, NOAA, UW NANOOS*		**$1,445,000**	**$1,075,000**	**$9,450,000**
A5. Physical characteristics & phytoplankton production - Upgrade the three ORCA buoys in Puget Sound so they can collect surface wind & solar information. Provide support to NANOOS.						Broad application beyond addressing priority 9 in BSWP. PSEMP appropriate target for LT monitoring, but should be highlighted in BSWP. Funding = PSC Southern Endowment Fund. Real future need likely includes covering some of in-kind.	funded for 2 yrs - ongoing	$60,000	$75,000	$1,500,000
A6. Zooplankton - Establish a puget sound wide zooplankton sampling program to assess the salmon prey field & establish ecosystem indicators to evaluate change over time						Broad application beyond addressing priority 9 in BSWP. PSEMP appropriate target for LT monitoring, but should be highlighted in BSWP. Funding = PSC Southern Endowment Fund. Real future need likely includes covering some of in-kind.		$325,000	$250,000	$450,000
A7. Juvenile Chinook & coho salmon - Determine where critical growth periods are & factors affecting growth & survival (prey, water quality, competition, predation by other fish)						PSEMP appropriate target for LT monitoring, but should be highlighted in BSWP. Funding = PSC Southern Endowment Fund (50%), SRFB (25%), WA Sea Grant (25%). Real future need likely includes covering some of in-kind.		$1,060,000	$750,000	$7,500,000

Salish Sea Marine Survival Project - Puget Sound Chinook & Coho Studies w/ focus on 2014-2015	**Timeline, 201-**					**Relevance to BWSP** All address priority 9 & should be listed in BWSP	**Status**	**Funded**	**Remain Cost**	**In Kind**
Top Down Studies & Other Work - *Targeted studies of potential contributing factors (disease, predation, toxics, aquaculture impacts , etc). Process studies to compliment sampling program & build out to fundamental drivers of survival. - Distributed bet. U.S. - Canada to address unique issues & cover more ground*	*4*	*5*	*6*	*7*	*8*			*$810,000*	*$1,825,000*	
A8. Hydroacoustic-midwater trawl survey - Night surveys to assess competition between salmon & forage fish, & the buffer effects of forage fish on predation						list in BWSP	not funded		$120,000	
A9. Analyze Existing Adult Scales/Otoliths to Evaluate Life-History Strategies, Growth, Size-at-Age, & their Effects on Survival						list in BWSP	not funded	$70,000	$90,000	
A10. Calibrate Techniques for Estimating Growth - calibrate multiple techniques (otolith, scale, IGF) used						list in BWSP	not funded		$40,000	
A12. Evaluate the Effect of Salish Sea Residency on the Marine Survival of Puget Sound Chinook & Coho - Use toxics signatures & otolith microchemistry to discriminate between resident & migratory life histories						list in BWSP	not funded	$70,000	$50,000	
A13. Puget Sound Steelhead Early Marine Survival Research - See Table X										
A16. Disease as a Contributing Factor - First evaluating nanopheytus in steelhead, but will build out to broader disease profiling once new techniques are fully developed by K. Miller-Saunders in Canada						list in BWSP	partial funding	below, in steelhead	$175,000	
A17. Contaminants as Contributing Factor - Complete the contaminants profile in juvenile Chinook. Samples collected during mid-water trawls will be processed & added to lower river & estuary samples. Perform any followup necessary.						list in BWSP. Funding = $140k DOE/EPA, $30k PSC Southern Endowment Fund	partial funding - ongoing	$170,000	$150,000	
A22. Harmful Algae Impacts - Exp& sampling & perform more direct evaluation of impacts to juvenile salmon survival						list in BWSP	not funded		$200,000	
A23. Next Steps (2016 & Beyond), e.g., predation by marine mammals & birds, nutrient loading, etc - to be developed in subsquent years						list in BWSP	not funded	$500,000	$1,000,000	

Salish Sea Marine Survival Project - Puget Sound Steelhead Studies w/ focus on 2014-2015	**Timeline, 201-**					**Relevance to BWSP** All address priority 9 & should be listed in BWSP	**Status**	**Funded**	**Remain Cost**	**In Kind**
	4	5	6	7	8					
1- 5. Steelhead marine survival trends & correlations w/ life-history & ecosystem factors						list in BWSP. Funding = WA State Appropriation	Funded - ongoing	$55,000		
6. Genome wide association study (GWAS) to determine whether there are inherent differences between steelhead that die or survive in Puget Sound						list in BWSP. Funding = WA State Appropriation	Funded - ongoing	$45,000		
7-10. Field studies to identify the locations, rate & timing of mortality & evaluate disease, toxic contaminants, genetics, & predator-prey interactions to reveal the direct & underlying causes of mortality						list in BWSP. Funding = WA State Appropriation	Funded - ongoing	$620,000		$800,000
11. Ecosystem indicators & modeling - to evaluate effects of multple factors (see A3-A4. of Chinook & coho work plan)						see A3-A4. of Chinook & coho work plan				
Next steps to provide scientific basis for managemen actions - to be developed in 2015						list in BWSP	Not Funded		$900,000	
Total Cost						In kind largely WDFW, PS Treaty Tribes, NOAA, USGS field work; UW NANOOS; & equipment (e.g. acoustic telemetry receivers)		$720,000	$900,000	$800,000

Research gaps in the social sciences

Humans are both the cause of and the opportunity for addressing the majority of recovery challenges such as ocean acidification and salmon habitat loss. At the same time, the Puget Sound Partnership is tasked with restoring the Puget Sound for human quality of life. On the immediate horizon, we need to synthesize and conduct social science to better link the pressure assessment to accurate human drivers and human wellbeing outcomes, to develop appropriate and viable implementation strategies, and to monitor the effect of restoration strategies on human wellbeing or quality of life.

Gaps in social science research for the 2014-2016 Biennial Science Work Plan were identified via a participatory workshop in October 2013 involving 17 social scientists from public agencies, universities and consulting firms working throughout the Puget Sound region. Information was gathered during small and large group sharing across four social domains. Items listed in Table 8 were identified as candidates for priorities, based on a qualitative highlighting of the topics participants felt were either immediate or critical to respond to Puget Sound recovery (no attempt was made to rank these candidates).

Table 8. Gaps in Social Science Research for Puget Sound (from Biedenweg and Nelson 2013). Categories are Economics (E), Governance (G), Human Behaviors (HB), Psychological and Physical (P&P), Social and Cultural (S&C).

Category	Social Science Research Topic
E	Identification and valuation of Puget Sound specific ecosystem services
E	Behaviors of natural resource industries (services and products, corporate-social responsibility, corporate green practices, when and why corporations set a good example)
E	Impact of large corporate natural resource ownership and opportunities. Overview of the big economic picture and the alternatives to the standard processes
E	The economic consequences of recovery actions
E	Effect of changing market land values, as they create an incentive for development
G	Institutional enablers and barriers to connection to nature (i.e. paying for park access passes)
G	Institutional dimensions of Puget Sound recovery (depth needed, generalizable, operable)
G	Internal PSP institutional diagnostic analysis (how the agency is functioning internally and with external relationships; includes broader lead organizations)
G	Energy, renewables, and utilities and the relationship to Puget Sound.
G	Floodplain by Design as an area to test or explore different governance structures to negotiate trade-offs between multiple objectives (salmon, flood control, etc.)
G	How local elected officials implement recovery actions in their local watersheds
G	The role of local technocrats (technical people within local governments)- what they are doing and why?
G	Science-policy interface. Decision making tools and how they integrate natural and social science research and information, and the relationship between scientists and decision makers and funders
G	Policy analysis and program evaluation (e.g. identifying conflicting mandates and identifying available tools and "policy levers")
G	The role of decision making frameworks and stakeholder participation.
HB	Forest/land/zoning conversion data for other counties
HB	Audience segmentation of shoreline landowners
HB	How to motivate children's environmental behaviors
HB	An analysis of private landowner stewardship behavior/incentive programs
HB	The varying effects of large and/or corporate landowner incentives
HB	Existing and potential policy context for behavior change
HB	Analysis of unanticipated behaviors in response to policies
HB	How built form influences behavior (eco-districts combining green building design and community social values, salmon districts?)
HB	Suburbanization of poverty
P&P	Tribal psychological and spiritual health specific to the natural environment
P&P	Non-Tribal spiritual/psychological benefits associated with the experience of the natural environment; rituals; cultural traditions
P&P	Contaminants/Quality of upland resources (deer, birds, other edible natural resources; urban foraging)
P&P	Connect emergent contaminant research to physical health and human behaviors
P&P	An analysis of meaning for different Puget Sound populations, to better understand how to motivate people to adopt behaviors (tied to spiritual)
P&P	Relationship between wellbeing and relevant behaviors, with breakouts by demography (perhaps by combining PSP surveys to allow for these analyses)
P&P	The application of social marketing research to Puget Sound Recovery
P&P	The determinants of a sense of empowerment, particularly of children (can we make a difference?)
P&P	Non-Tribal natural resource use and informal resource economy (food, etc.) by all populations. To what extent does it influence their psychological and physical health?
P&P	Better understanding of the dimensions of human wellbeing/quality of life and their links to ecosystem recovery (what do people value? How can this inform indicator choices and strategy development)
P&P	Psychology of built environments
S&C	Corporate Culture (behaviors, incentives, cultural v. economic, participation and stewardship, strategy, ethnography, communication, philanthropic options)
S&C	Meta-analysis of existing social science research and surveys (sample range, comparisons, synthesis)
S&C	The study of place-dependence

Puget Sound Ecosystem Monitoring Program

Membership of the Puget Sound Ecosystem Monitoring Program (PSEMP) is comprised of environmental monitoring professionals, researchers, and data users from federal, tribal, state, and local government agencies, universities, non-governmental organizations, watershed groups, businesses, and private and volunteer groups. PSEMP is organized around a Steering Committee with representatives from 23 different partner organizations, and 10 technical Work Groups focused on key ecosystem topic areas (e.g. marine waters, toxics, nearshore, forage fish & food webs, etc.): *https://sites.google.com/a/psemp.org/psemp/home*

The objective of PSEMP is to create and support a collaborative, inclusive, and transparent approach to regional monitoring and assessment that builds upon and facilitates communication among the many programs and efforts operating in Puget Sound. PSEMP's fundamental goal is to assess progress towards the recovery of the health of Puget Sound.

PSEMP monitoring gaps

Through much of 2012-2013, the ten PSEMP Work Groups were tasked with compiling an inventory of current monitoring activities and evaluating monitoring gaps associated with the Vital Sign indicators, strategic initiatives, and other key topics related to understanding and tracking the health of Puget Sound. The final monitoring inventories and work group gap summaries can be found on the PSEMP web site:
https://sites.google.com/a/psemp.org/psemp/home

The process used by each work group, the contributing participants, and the logic or rationale for these suggestions are described in greater detail in the individual work group summaries found on the PSEMP web site: *https://sites.google.com/a/psemp.org/psemp/monitoring-inventories-gap-analyses/gaps-beyond-the-vital-signs.*

The most important ecosystem monitoring gaps were identified by PSEMP, based on an assessment conducted over the period 2012-2014 (Table 9). The assessment was led by PSEMP technical workgroups and individual Vital Sign Indicator Leads, and involved over 200 subject experts, regional monitoring program leaders, scientists and data users across Puget Sound. Results are based on detailed inventories of current monitoring, followed by an evaluation of monitoring gaps and information needs critical to tracking the condition and recovery of Puget Sound.

Evaluation of gaps was based primarily on their importance to tracking ecosystem conditions and trends. To improve management relevance, gaps were sorted into categories, including:

- Gaps limiting our ability to track or report the Puget Sound Vital Signs
- Gaps related to the three Strategic Initiatives described in the Puget Sound Action Agenda (stormwater, shellfish, habitat)
- Gaps related to other critical science or management priorities

The total cost to address all 56 high priority monitoring gaps was estimated at $7.36 M in one-time (FY16-18) costs, with on-going costs of $12.5 M annually thereafter. The cost for any individual category of gaps is less than the total and estimates are provided in the report.

However, many gaps relate to more than one category and consequently, individual cost totals cannot be summed.

Monitoring gaps related to other science and management priorities

The PSEMP assessment addressed monitoring and information gaps related to the most important aspects of the condition and changes over time of the Puget Sound ecosystem. While many of these gaps are clearly related to either an existing Puget Sound Vital Sign or one of the three Strategic Initiatives, a number of our high-priority gaps address other critical science or management concerns not captured under an existing Vital Sign or Strategic Initiative. These include several emerging issues that have the potential to force a fundamental shift in our recovery strategies - and which therefore clearly warrant our attention. As a first step, improving our ability to monitor and track these issues is fundamental. These include:

- **Ocean acidification:** PSEMP supports the monitoring recommendations included in the Blue Ribbon Panel report on Ocean Acidification, and identify a number of related water quality, oceanographic, and modeling gaps critical to tracking this issue and it's many implications.

- **Climate change:** Has potential ramifications in myriad ecosystem functions including terrestrial and freshwater aquatic systems, ocean dynamics, and species/food web interactions. At a minimum, this issue warrants improved monitoring to detect large-scale ecosystem shifts, regional implications, and a broad range of potentially important species responses.

- **Food web dynamics (phytoplankton, zooplankton, forage fish, jellies):** Much of what we most enjoy and seek to restore in Puget Sound depends on a healthy, functioning food web, yet this is a topic area which is grossly under-studied and for which we have relatively little long-term data. This issues captures everything from potential shifts in the primary producers that form the base of the food web, to harmful algal blooms, and the zooplankton and forage fish communities which are the main food of salmon and many other fish and marine mammal species.

- **Species status (including ESA assessments and other species declines):** Long-term declines in species populations are an important indicator of the health of Puget Sound. Certain species of salmon, rockfish, forage fish, and many birds and marine mammals have declined significantly. Long-term monitoring to track abundance not only of species already in decline, but also species which may be vulnerable, is fundamental to adaptive management.

Table 9. List of 56 high priority monitoring gaps and funding needs across 13 technical topic areas. Gaps include: 1) new monitoring programs needed to collect and report data where none currently exist, 2) expanding current monitoring where coverage is incomplete or not representative, and 3) gaps related to data management, analysis, or reporting.

ID	PSEMP High Priority Monitoring Gaps	Vital Sign gap	Strategic Initiative			Science Issues				One-time costs	Annual operating costs ($)
			Storm-water	Habitat	Shellfish	Ocean Acid'n	Climate Change	Food Webs	Species status	($)	
	Stormwater										
1	Flow monitoring in small streams.		Yes	Yes	Yes					250,000	300,000
2	Monitor conditions in marine nearshore areas outside Urban Growth Area (UGA) boundaries, specifically for sediment chemistry, toxics in mussels, and bacteria.		Yes		Yes						200,000
3	Monitor presence and persistence of current urban and agricultural use pesticides, esp. in receiving water sediments.		Yes		Yes					150,000	
	Toxics										
4	Restore/maintain monitoring activities to support the Toxics in Fish Vital Sign.	Yes	Yes							100,000	515,200
5	Special studies under a Biological Observation System. First Priority is to evaluate magnitude and health effects of Chemicals of Emerging Concern (CECs) in/on Puget Sound biota.		Yes								226,500
6	Monitoring of Toxics in Harbor Seals (or other marine mammals).		Yes								150,000
7	Monitoring of Toxics in Mussels.		Yes		Yes						250,000
8	Enhancements to Toxics in Sediments Vital Sign: re-establish in-house benthic invertebrate taxonomic expertise.		Yes								241,000

ID	PSEMP High Priority Monitoring Gaps	Vital Sign gap	Strategic Initiative			Science Issues				One-time costs	Annual operating costs ($)
			Storm-water	Habitat	Shellfish	Ocean Acid'n	Climate Change	Food Webs	Species status	($)	
	Nearshore: shoreline armoring, estuaries, eelgrass										
9	Shoreline Armoring: Process-based monitoring at the drift cell scale related to functions of the nearshore and any "thresholds" of percent armored.			Yes						500,000	
10	Physical covariates of biotic signals: Bathymetry/topography (i.e. elevation), substrate composition (e.g. grain size), and sediment accretion and transport. General aim to monitor nearshore physical attributes that shape nearshore biological communities.			Yes						500,000	
11	Estuaries: Data collection and analysis improvements are needed that standardize estuarine area footprints, baseline conditions, and restoration metrics.	Yes		Yes						250,000	
12	Shoreline Armoring: Data collection improvements to improve precision of the current baseline. Supplement HPA data with local shoreline permitting, federal permits, and some directed field validation including improved mapping of non-permitted actions.	Yes		Yes						125,000	
13	Eelgrass: Evaluate potential stressors that have led to observed losses at monitoring sites (DNR Stressor Response Program).			Yes					X		200,000

ID	PSEMP High Priority Monitoring Gaps	Vital Sign gap	Strategic Initiative			Science Issues				One-time costs	Annual operating costs ($)
			Storm-water	Habitat	Shellfish	Ocean Acid'n	Climate Change	Food Webs	Species status	($)	
	Terrestrial: Land use land cover, floodplains										
14	Collect spatial footprint data for restoration projects in Puget Sound. Current data is largely just point locations.			Yes						50,000	
15	Map priority ecosystems/habitats so that dynamics can be assessed by change detection.			Yes							100,000
16	LULC Indicator: Reporting is limited by resolution and schedule of satellite products provided by federal government. Support full NAIP coverage and analysis: change analyses currently limited by funding/capacity.	Yes		Yes							125,000

ID	PSEMP High Priority Monitoring Gaps	Vital Sign gap	Strategic Initiative			Science Issues				One-time costs	Annual operating costs ($)
			Storm-water	Habitat	Shellfish	Ocean Acid'n	Climate Change	Food Webs	Species status	($)	
	Marine Waters										
17	Restore/maintain monitoring activities to support the Swimming Beaches Vital Sign.	Yes	Yes								285,000
18	Deploy and maintain an Orca buoy seaward of Admiralty Sill (i.e. Straits of Juan de Fuca) to obtain high temporal resolution, vertically-resolved measurements of physical and chemical variables at a minimum, (biological desired).				Yes	X	X			25,000	100,000
19	Enhance high resolution monitoring of physical and chemical variables (biological desired) in Puget Sound basins and mixing zones to better determine transort, change, and human alteration.				Yes	X	X				750,000
20	Conduct high spatial and temporal resolution surveys of zooplankton and phytoplankton species, abundance, and rates (production, respiration, and sinking).				Yes	x	X	X	X		515,000
21	Ocean acidification: Follow the recommendations of the Blue Ribbon Panel on Ocean Acidification in Washington.				Yes	X	X				237,500
22	Add wind sensors existing and new moorings to obtain wind data from over the water (inside Puget Sound).					X	X				185,000

ID	PSEMP High Priority Monitoring Gaps	Vital Sign gap	Strategic Initiative			Science Issues				One-time costs	Annual operating costs ($)
			Storm-water	Habitat	Shellfish	Ocean Acid'n	Climate Change	Food Webs	Species status	($)	
	Freshwater										
23	Water Quality Index - bring diverse data sets into alignment for regional reporting. Data are being collected but not used to report on Vital Sign.		Yes	Yes			X			137,000	370,000
24	Integrated monitoring at the watershed scale (including small streams, and including status & trends monitoring of salmon habitat at the watershed scale). Implementation of statistical sampling designs so that water quality and habitat data is coordinated with salmon recovery and other watershed scale efforts.		Yes	Yes			X				150,000
25	Connect instream flow data for fish use to surface and groundwater use and withdrawal. These data are complicated and challenging to connect but are needed for planning and salmon recovery.		Yes	Yes						100,000	50,000
26	Lake Monitoring, currently thousands of lakes with minimal monitoring for algal blooms (which may affect shellfish downstream), toxics and nutrients.		Yes	Yes							100,000
27	Stream restoration for B-IBI targets. We need to track stream with restoration actions through time to learn what is working and duplicate success to other watersheds.		Yes	Yes							100,000

ID	PSEMP High Priority Monitoring Gaps	Vital Sign gap	Strategic Initiative			Science Issues				One-time costs	Annual operating costs ($)
			Storm-water	Habitat	Shellfish	Ocean Acid'n	Climate Change	Food Webs	Species status	($)	
	Birds										
28	Evaluate existing, multi-year marine bird datasets to: 1) intergrate and report existing info about population size S&T at local->regional scales, for all or a subset of 32 focal spp. and 2) Determine whether spatial and temporal coverage and design of existing monitoring is adequate for assessing population size of all or a subset of 32 focal spp.	Yes							X	160,000	
29	Population size surveys targeting those focal species of marine birds breeding in Puget Sound that are not adequately captured by existing surveys.								X		100,000
30	Collect data and report on breeding success and diet of a broader representation of focal species of marine birds breeding in Puget Sound, or increase the spatial coverage of those focal species currently being monitored.							X	X		80,000
31	Investigate what are natural drivers of, and human pressures on, focal marine bird population size both inside Puget Sound and outside of Puget Sound and their relative importance.			Yes					X	80,000	

ID	PSEMP High Priority Monitoring Gaps	Vital Sign gap	Strategic Initiative			Science Issues				One-time costs	Annual operating costs ($)
			Storm-water	Habitat	Shellfish	Ocean Acid'n	Climate Change	Food Webs	Species status	($)	
	Mammals										
32	Conduct systematic survey of harbor porpoise at the scale of inland waters of Washington.								X		438,000
33	Conduct systematic survey of harbor seals at the scale of inland waters of Washington.								X		70,000
34	Conduct seasonal and year-round census of Southern Resident Killer Whale to get at survival/mortality and fecundity.								X		230,000
35	Building on existing long-term demographic studies (survival, reproduction, fecundity), pursue regular monitoring of harbor seal physiological status, symptoms of disease or trauma and signs of disease, contaminants.								X		190,000
36	Gather stranding data on all species of marine mammals, with priority toward harbor porpoise. To this end, sustain or enhance the Prescott Marine Mammal and Rescue Assistance Program.								X		266,000

ID	PSEMP High Priority Monitoring Gaps	Vital Sign gap	Strategic Initiative			Science Issues				One-time costs	Annual operating costs ($)
			Storm-water	Habitat	Shellfish	Ocean Acid'n	Climate Change	Food Webs	Species status	($)	
	Forage Fish and Food Webs										
37	Design a comprehensive study focused on evaluating causes for the decline (and limiting recovery) of Cherry Point herring.			Yes				X	X		TBD DNR is drafting scope of study
38	Collect biological samples of adult herring (age/size/genetics).							X	X		140,000
39	Conduct zooplankton and icthyoplankton surveys (esp for estimating abundance of sand lance, other forage fishes and rockfish).							X			230,000
40	Monitor predator diets (predator fishes, seals, birds).							X			60,000
41	Conduct Sound-wide, seasonal (systematic) field surveys of forage fish (and jellies) for diversity, abundance, and other attributes.	Yes						X	X		800,000 (96,188 for vital sign)

ID	PSEMP High Priority Monitoring Gaps	Vital Sign gap	Strategic Initiative			Science Issues				One-time costs	Annual operating costs ($)
			Storm-water	Habitat	Shellfish	Ocean Acid'n	Climate Change	Food Webs	Species status	($)	
	Salmonids										
42	Improve Chinook spawner abundance estimates with measures of variance.	Yes	Yes	Yes					X	1,550,000	1,220,000
43	Expand steelhead spawner abundance surveys into areas having little or no monitoring (including measures of variance).		Yes	Yes					X	830,000	350,500
44	Improve Chinook juvenile abundance estimates and smolt to adult return estimates for existing monitored watersheds.		Yes	Yes					X	670,000	1,200,000
45	Improve steelhead juvenile abundance estimates and smolt to adult return estimates for existing monitored watersheds.		Yes	Yes					X	220,000	653,000
46	Status and trend monitoring of nearshore habitat for salmonids.		Yes	Yes							400,000

ID	PSEMP High Priority Monitoring Gaps	Vital Sign gap	Strategic Initiative			Science Issues				One-time costs	Annual operating costs ($)
			Storm-water	Habitat	Shellfish	Ocean Acid'n	Climate Change	Food Webs	Species status	($)	
	Rockfish										
47	Ongoing WDFW ROV surveys and method refinements to estimate current population abundance and spatial distribution of adult and juvenile rockfishes (esp abundance of the DPSs of yelloweye rockfish, canary rockfish, and bocaccio).								**X**		340,000
48	Habitat use of juvenile and adult rockfish. Home range size (both the mean and variance) of adult rockfishes.			**Yes**						300,000	
49	USGS completion of benthic habitat mapping and characterization throughout Puget Sound using tools such as multibeam echosounders, side-scan sonar, and subbottom seismic reflection profile mapping systems (as has been completed within some of the San Juan Archipelago).			**Yes**						150,000	
50	Scope and monitor a priority threat to rockfish recovery (e.g. degraded water quality, predation, artificial propagation of salmon, lingcod, derelict gear, changing biotic condition).								**X**	200,000	

ID	PSEMP High Priority Monitoring Gaps	Vital Sign gap	Strategic Initiative			Science Issues				One-time costs	Annual operating costs ($)
			Storm-water	Habitat	Shellfish	Ocean Acid'n	Climate Change	Food Webs	Species status	($)	
	Modeling										
51	Maintain two large-scale Puget Sound circulation and water quality models (Salish Sea Model; MoSSea) and supply model output to other Puget Sound scientists. Includes hardware maintenance, model code updates and corrections, and basic staffing to respond to data requests.		Yes		Yes	X	X				260,000
52	Model Development: Annual priority improvements to the Salish Sea and MosSSea models. Example: improve fine scale circulation and water quality predictions in bays and inlets.		Yes		Yes	X	X				200,000
53	Large scale operational model for Salish Sea (24-7 simulations) at the finest resolution practicable. Salish Sea or MoSSea (cost estimate is for one model).				Yes	X	X			300,000	100,000
54	Studies to improve understanding of biogeochemical interactions and associated model constants (e.g., kinetic rates of primary production and nitrogen cycling).				Yes		X	X		350,000	
55	Development of an integrated Salish Sea ecosystem model featuring circulation (MoSSea or Salish Sea), food web interactions, habitats, and management actions, probably in the Atlantis ecosystem software.			Yes	Yes	X	X	X		360,000	

ID	PSEMP High Priority Monitoring Gaps	Vital Sign gap	Strategic Initiative			Science Issues				One-time costs	Annual operating costs ($)
			Storm-water	Habitat	Shellfish	Ocean Acid'n	Climate Change	Food Webs	Species status	($)	
	Human Wellbeing										
56	Data collection and reporting system will be needed to support the anticipated human wellbeing indicators.	Yes									35,000
	Total: all one-time (FY16-18) costs									**7,357,000**	
	Total: all on-going (annual) costs										**12,512,700**

Conclusions

It is recognized that any prioritization process that the Science Panel might undertake would not align with the decision situations that others face when selecting areas of strategic focus or topics for investment in scientific investigations. Therefore, we encourage prospective sponsors of recovery science in Puget Sound to view the recommendations presented above as relevant and timely topics that may align with their identification of research priorities.

Among the PSEMP high priority monitoring gaps presented above are a number of items that would improve the scientific information available to the Partnership to understand the status of ecosystem recovery and progress being made in its three strategic initiatives. Given the key role of monitoring in managing and adapting ecosystem recovery, the Science Panel commits to working with policy makers (e.g., in the Partnership organization, in the Governor's office) to (1) understand what is not yet monitored and what could be learned with additional monitoring information and (2) develop funding for the programs and studies that deliver information that is significant to policy makers.

We note that some recommendations presented here are better validated than others, but all the topics presented in Part III are backed by the credibility of scientists currently working on ecosystem recovery in Puget Sound. As we develop work plans for future biennia, we encourage scientists, program and resource managers, and policy makers to collaborate on reports that recommend scientific investigations that would address uncertainties and knowledge gaps that are relevant to policy and management decisions.

Part IV: Recommendations for Improvement

To this point, the report has assessed how science is informing recovery of Puget Sound within the current biennium, with recommendations of relevant and timely topics for research in the coming biennium. The purpose of this section is to describe an approach to better inform recovery based on current science, community input and pragmatism. This part begins with a review of the status of science in support of Puget Sound recovery.

Status of science in support of ecosystem recovery

According to the latest *State of the Sound* report (2013) we are half way to the statutory 2020 'deadline' for recovery, but most status and trends indicators ('Vital Signs') have not advanced much, if at all, towards their targets, and some, such as Southern Resident killer whales, have lost ground. Puget Sound recovery practitioners are not alone in expending great effort and still finding recovery elusive. A recent meeting of lead scientists representing Puget Sound and six other large coastal ecosystems in the US revealed that to varying extents all were struggling not only with this, but also with other shared challenges (Table 10). Insights that stood out from proceedings as particularly instructive for the application of science to ecosystem recovery are related in Georgiadis et al. (2014), and those that pertain to Puget Sound are repeated below.

Table 10. Shared challenges among recovery strategies of seven coastal ecosystems.

1	Recovery science for a given ecosystem is often "fractured", proceeding without coordination among largely independent groups.
2	Setting priorities under uncertainty, not only among multiple recovery targets and actions, but also for the science needed to reduce uncertainty and support decision-making.
3	The problem of defining and detecting causal relationships between stressors, actions, and ecosystem responses.
4	Managing expectations about recovery: ecosystems often take so long to respond to remedial action it is hard to know if they are responding at all.
5	The theory of adaptive management is far easier to grasp than to apply.
6	Effectively communicating science to policy and decision makers and the clear communication of policy goals and decision requirements from policy makers to scientists.
7	All were aware that applying and integrating social sciences into ecosystem restoration promise great gains, but have struggled to achieve this goal.

The problem of not progressing towards recovery targets is compounded by not knowing *why*. The severity of this problem was highlighted at a recent Science Panel meeting by an observation about the *Intensively Monitored Watersheds* program. This program was set up specifically to understand the complex relationships controlling salmon responses to habitat changes (in Washington state), and to detect responses by salmon to a set of restoration actions, by concentrating monitoring and research efforts at a few strategically selected locations (*http://www.ecy.wa.gov/programs/eap/imw/index.html*). After 10 years, few responses have been detected. This observation has implications for expectations of informed recovery at the level of the Puget Sound ecosystem.

The program has yielded substantive information on the relationships between abundance, productivity, spatial structure and diversity of Chinook and watershed scale processes and habitat. Yet there are many possible reasons for a lack of response. One is that recovery targets are not sensitive to change on the time scale proposed and expected by policy makers. Another is that the number and scale, most likely, of restoration actions have been insufficient, or address the wrong cause or combination of causes. Even so, there is pressing need to better understand the impact and effectiveness of recovery actions.

For ecosystems represented at the workshop, there were few reported instances of even partial recovery (e.g., blue crab in Chesapeake Bay), but these were instructive. For example, progress towards recovery targets tended to be greater in recovery strategies that focus on fewer targets. Chesapeake Bay's recovery strategy targets only three stressors (nitrogen, phosphorus, and sediment levels in rivers flowing into the Bay). By contrast, more than 20 recovery targets have been selected for Puget Sound (depending on how they are defined). Progress may be imperceptible because capacity and resources have been spread too thinly over too many targets and across too large an area for recovery gains to be detectable. A related possibility is that system responses are nonlinear and manifested only after cumulative effort surpasses threshold levels that have not yet been reached for most targets. It may also be that marketing a simpler strategy garners greater public and thus political support. Even if these are valid, in complex systems like Puget Sound, narrowing the scope of the recovery strategy to a feasible yet effective number of targets turns out to be one of the greatest challenges of all. This is because the number of potential targets is large, many of them interact with each other, and much of the information is lacking that is required to rank them by potential to yield greatest recovery gains.

A further difference among ecosystem recovery strategies represented at the workshop was that some were more explicitly model-based than others. For example, in the Chesapeake Bay region, management of stressors depends on sophisticated models (for example, that simulate processes determining pollutant concentrations), finely tuned regulatory systems, and close coordination among state and federal agencies. From the assessment in Part I above it is evident that models describing 'how nature works' are reasonably prevalent among ongoing and recently completed research projects in Puget Sound, yielding critical insights into ecosystem processes. But too often it is left implicit how research findings (especially model outputs) will be adapted and applied to recovery. There is great need for synthesis of research findings and assessment of their implications for recovery. This would not only instruct the recovery strategy, but also inform policy makers and the public about the recovery process.

Many of the reasons that might account for little observable progress towards recovery are symptoms of a more inclusive explanation: that adaptive management (AM) is difficult to apply at the ecosystem level. Practitioners at the workshop agreed that applying AM to large and complex ecosystems is challenging, but nonetheless re-affirmed unanimously that AM should remain the default approach to recovery, for three main reasons: there are too many unknowns for alternative approaches to offer plausible advances; to chart a cost-effective course towards recovery; and to demonstrate net benefits of actions in order to justify continued funding for recovery (or, if actions do not deliver desired effects, at least to understand *why*). Discussion about relative expenditure on monitoring and AM among ecosystems revealed an average of about 15% of the total spent on recovery. This was an amount limited more by what funding agencies were prepared to commit than by what is needed to address critical uncertainties.

In Puget Sound, AM was adopted as the default approach (Puget Sound Partnership 2010, Redman et al. 2013). But AM has been applied in a patchy and incomplete manner, partly because of insufficient resources. Since recovery strategies for threatened and endangered species are availed greater resources, it is no coincidence that AM is better developed for, say, Chinook salmon than for non-endangered targets in Puget Sound (viz. *Framework for development of Monitoring and Adaptive Management Plans*, the Intensively Monitored Watersheds program, and the budget of project no. 29 in the inventory of projects). It follows that resources on a similar scale would be required to apply AM to every recovery target, endangered or not. Because funding at that scale for all targets remains improbable, questions about the effective number of recovery targets for Puget Sound, and the level of funding that would be required to make measured progress towards all targets, should be revisited.

Recommendation: integrate science into the development of implementation strategies for each target

Two recent developments offer promising ways to identify, prioritize, and achieve recovery research priorities that improve upon approaches used to date. The first is resurgent support for creation of an 'implementation strategy' for each recovery target. The Science Panel understands that implementation strategies are intended to explicitly define and document the mechanisms and causal pathways by which recovery targets are expected to be met, the steps, actions and coarse (order of magnitude) levels of resources that would be needed to achieve a given recovery target, and the actors needed to carry out these steps and actions. The panel envisions that these could be presented in conceptual diagrams and accompanying narrative expressing detailed versions of 'results chains' (CMP 2013, or other depictions of 'theories of change' or 'pathways of effects'). The other consequence of developing implementation strategies is that it can focus the implementer and stakeholder conversation on the intentions of the management conference, that is where we need to put our collective efforts to achieve results. This focus is a necessary part of understanding where scientific uncertainty creates disagreement among policy makers, and more importantly on how to proceed – in particular where a lack of science impedes agreement to move forward together. This is one way to identify decision critical science.

If everything were known about how to achieve a given recovery target, the implementation strategy would resemble, say, a plan to build a bridge. For ecosystem targets, however, it is rarely the case that enough is known, and no new knowledge is needed, to attain a recovery goal. For most, there is uncertainty about how outcomes are affected by natural processes, how these are impacted by humans, or how restoration and protection actions bring about recovery. It is exactly under this kind of uncertainty that adaptive management, by the measured application of science, improves the likelihood of advancing towards recovery. Defining a strategy to achieve each recovery target is a key step in the programmatic cycle of AM (CMP

2013). Through this step, hypotheses and assumptions are made explicit, thereby promoting communication and use of recovery science, facilitating identification and implementation of science-informed recovery actions, and providing a basis for evaluating and adapting hypotheses, assumptions, and recovery actions. In this context, therefore, the term ‘implementation strategy’ includes and entails the integration of science to address critical uncertainties.

Used in this way, implementation strategies should address and resolve many of the difficulties relating to identification and selection of decision-critical research that were highlighted in Part I of this report. Once an implementation strategy is designed and documented it becomes possible to separate layers showing the junctures at which 1) research is needed to resolve a critical uncertainty (including models and social science), 2) monitoring is needed to assess effectiveness of actions, 3) policy changes are required; 4) costs can be estimated to assess cost-effectiveness, and 5) time will be needed for social and ecological processes to deliver expected outcomes. In this way, not only are the essential elements of recovery (science, policy, monitoring, etc.) featured, but their interactions can also be represented. For any given time and purpose (such as the preparation of a BSWP), the list of research priorities can be drawn up simply by combining the ‘research layers’ from each implementation strategy. The list of monitoring and policy priorities would be similarly derived. It becomes at least conceivable to estimate and compare the cost and cost-effectiveness of alternate paths and actions, order actions into a logical time frame, and expose common and conflicting goals within and among strategies.

The Science Panel endorses creation of implementation strategies as a key step in the adaptive approach to Puget Sound recovery, and recommends they be supported accordingly. Initial emphasis should be on development of implementation strategies for each target, in which uncertainty, and the research required to address uncertainty, is an integral feature.

Recommendation: implementation strategies for each recovery target be defined by separate ‘recovery groups’

The second promising development arose during a December 2013 workshop convened by the Science Panel to explore the feasibility of creating implementation strategies for recovery targets in Puget Sound. A subset of workshop participants focusing on Pacific herring discussed how a ‘recovery group’ comprised of applied scientists, experienced managers, and other experts could develop and advance a recovery strategy for herring, much as ‘recovery teams’ do for endangered species. Given funding constraints, recovery groups could fill only a few of the roles that are typically performed by recovery teams (which is why we distinguish groups from teams), but defining implementation strategies should be included.

This notion is not new. In 2011 PSP convened ‘inter-disciplinary teams’ to define ‘results chains’ targeting selected pressures. Strategies were sketched for many targets, but not completed or applied, partly because the teams were short-lived.

The Science Panel recommends that recovery groups should once again be convened from clusters of scientists, resource managers and recovery practitioners that already exist for many of the recovery targets within the Puget Sound restoration community (e.g. shoreline armoring, forage fish, floodplains, and estuaries). The key feature of this approach is that creation of implementation strategies would proceed ‘in parallel’ for each target. Beginning with definition of implementation strategies, recovery groups would guide the recovery of each target for the foreseeable future. They would need appointment, guidance, management, coordination, and long-term funding.

Once implementation strategies have stabilized, the panel recommends that funds should be awarded largely to projects – be they for research or implementation of recovery-related actions – that explicitly describe how topics featured in and justified by implementation strategies will be addressed. The next BSWP should summarize progress in the design and use of implementation strategies, including the identification of recovery research priorities, and descriptions of criteria by which attainment of research objectives will be assessed.

Science Panel's commitments

To help achieve these objectives, the Science Panel will:

- Support the definition and description of implementation strategies;
- Support the Partnership's selection of a group of implementation strategies to be created during the 2014-16 biennium;
- Develop advice about how science can be used by recovery groups to develop implementation strategies. This advice may specify approaches to and capacity for:
    - engagement of scientists in recovery groups,
    - synthesis of scientific understandings and advances that have accrued in relation to selected recovery targets, and
    - use of structured decision making (Gregory et al. 2012) to select steps and actions to include in implementation strategies.

We recognize the role of both science groups and policy making bodies in recovering Puget Sound. This science-policy partnership is especially important to effectively using implementation strategies as described here. To that end, we recommend that policy makers adopt a similar process to the one followed by the Science Panel. The results of their process may take the form of ECB commitments to support the definition and description of implementation strategies and support the Partnership's selection of a group of implementation strategies to be created during the 2014-16 biennium. They might also offer advice about how to engage implementers, managers, and policy-makers to develop implementation strategies, which might specify approaches to and capacity for:

- engagement of policy makers in recovery groups,
- synthesis of policy differences (values and interpretation of science) that have accrued in relation to selected recovery targets, and
- use of structured decision making (Gregory et al. 2012) to select steps and actions to include in implementation strategies.

Conclusions and outlook

The emphasis on creating implementation strategies by separate recovery groups is intended to meet several needs. One is to find additional ways to advance the research agenda for recovery, given the wide array of what are essentially equal priorities, and in the face of shrinking budgets. A second is to integrate science and policy more directly into the practice of recovery. A third is to specify strategies (that can be supported by policy) for attaining each recovery target, while implementing a style of adaptive management that is more informative about effectiveness and progress. The only way to achieve this exacting agenda is to spread the task of planning recovery strategies and guiding their implementation among groups of practitioners with the requisite experience and resources.

Until funds can be allocated to recovery groups, progress is expected to be limited. Even then, this approach to defining implementation strategies will test the limits of volunteerism. It is expected that several nascent recovery groups will explore the feasibility of this approach over the next year or two. The Science Panel will support these groups on issues relating to science and decision-making, and attempt to record their collective experiences accumulated during this exploration period, for the benefit of those that follow.

Creation of recovery groups would mark the fourth time that the effort of recovering Puget Sound has been subdivided (salmon recovery divides effort among 16 watershed groups, coordinated research and actions are divided among six Lead Organizations or LOs, and the task of integrating recovery planning and implementation is divided among nine Local Integrating Organizations, or LIOs). Ultimately, efficiencies should increase with coordination and alignment among these potentially intersecting paths, but no purposed mechanism (such as a steering committee) exists to steer and guide them. If and when a critical number of recovery groups deliver and begin to oversee implementation of recovery strategies, a level of coordination will be required that does not yet exist in Puget Sound, requiring capacity that includes but goes well beyond science.

This section concludes by summarizing the list of needs relating to recovery science that were expressed in this BSWP (Table 11).

Table 11. A list of needs relating to recovery science in this BSWP.

1	For a process to be developed by which the inventory of recovery research projects can be continuously updated (as opposed to recreating it anew every biennium) using a dedicated online database. Once operational, funding agencies should require grantees to enter project data into the database as funds are awarded.
2	For the BSWP to be published as far in advance of other work plans (including LO plans and Action Agenda Updates) as necessary to allow research recommendations to be acted upon, and funding provisions made (>6 months).
3	For sponsors of recovery research to consider recommendations and priorities listed in Parts III and IV of this document.
4	For effectiveness of recovery actions to be assessed, where appropriate, through effectiveness monitoring.
5	For *cost effectiveness* to guide planning and implementation of recovery priorities and actions.
6	For Priority Science Actions and their goals to be made sufficiently specific to permit assessments of progress.
7	For the scope of Puget Sound's recovery strategy (e.g. number of recovery targets) to be reduced, and / or funding to be increased, such that resources are sufficient to allow Adaptive Management to be applied to every target.
8	For 'implementation strategies' to be defined and documented for every target by a separate 'recovery group'.
9	For the PSP Science Panel to support the definition, characterization, and description of 'implmentation strategies'.
10	For results and findings of completed research projects to be synthesized and their implications for recovery assessed, focusing initially on recovery targets for which implementation strategies are to be prepared.
11	Where appropriate, for scientists conducting recovery research to be actively involved in the process of transforming their research results to actions, expecially in the design of implementation strategies by 'recovery groups'.
12	For Structured Decision Making to be applied in the design of implementation strategies where consensus among experts is elusive.
13	Once implementation strategies have been defined and documented, funds should be awarded largely to projects – be they for research or implementation of recovery-related actions – that explicitly describe how topics featured in and justified by implementation strategies will be addressed
14	For RFPs relating to recovery science to require proposers to describe how their projects will address PSAs (and elements of implementation strategies), and how results will be applied to recovery.

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Appendices

Appendix A

Statute relating to role of the PSP Science Panel and Biennial Science Work Plan

RCW 90.71.290 Science panel — Strategic science program — Puget Sound science update — Biennial science work plan.

(1) The strategic science program shall be developed by the panel with assistance and staff support provided by the executive director. The science program may include:
   (a) Continuation of the Puget Sound assessment and monitoring program, as provided in RCW 90.71.060, as well as other monitoring or modeling programs deemed appropriate by the executive director;
   (b) Development of a monitoring program, in addition to the provisions of RCW 90.71.060, including baselines, protocols, guidelines, and quantifiable performance measures, to be recommended as an element of the action agenda;
   (c) Recommendations regarding data collection and management to facilitate easy access and use of data by all participating agencies and the public; and
   (d) A list of critical research needs.

(2) The strategic science program may not become an official document until a majority of the members of the council votes for its adoption.

(3) A Puget Sound science update shall be developed by the panel with assistance and staff support provided by the executive director. The panel shall submit the initial update to the executive director by April 2010, and subsequent updates as necessary to reflect new scientific understandings. The update shall:
   (a) Describe the current scientific understanding of various physical attributes of Puget Sound;
   (b) Serve as the scientific basis for the selection of environmental indicators measuring the health of Puget Sound; and
   (c) Serve as the scientific basis for the status and trends of those environmental indicators.

(4) The executive director shall provide the Puget Sound science update to the Washington academy of sciences, the governor, and appropriate legislative committees, and include:
   (a) A summary of information in existing updates; and
   (b) Changes adopted in subsequent updates and in the state of the Sound reports produced pursuant to RCW90.71.370.

(5) A biennial science work plan shall be developed by the panel, with assistance and staff support provided by the executive director, and approved by the council. The biennial science work plan shall include, at a minimum:
   (a) Identification of recommendations from scientific and technical reports relating to Puget Sound;
   (b) A description of the Puget Sound science-related activities being conducted by various entities in the region, including studies, models, monitoring, research, and other appropriate activities;
   (c) A description of whether the ongoing work addresses the recommendations and, if not, identification of necessary actions to fill gaps;
   (d) Identification of specific biennial science work actions to be done over the course of the work plan, and how these actions address science needs in Puget Sound; and
   (e) Recommendations for improvements to the ongoing science work in Puget Sound.

Appendix B:

Institutions at which staff were contacted to request information about ongoing and recently completed projects, and recommendations for needed research.

County, State, and Federal Agencies
King Co. Science Section
Northwest Fisheries Science Center
Pacific Northwest National Labs
Puget Sound Partnership
USDA Forest Service – Pacific Northwest Research Station
USGS Forest and Rangeland Ecosystem Science Center
USGS Pacific Coastal and Marine Science Center
USGS Washington Water Sciences Center
USGS Western Fisheries Research Center
USGS Western Geographic Science Center
Washington Sea Grant
Washington State Department of Commerce
Washington State Department of Ecology
Washington State Department of Fish and Wildlife
Washington State Department of Health
Washington State Department of Natural Resources (Aquatics & Forestry)
Institutes
Center for Urban Waters
Center for Wildlife Ecology at Simon Fraser University
Coastal Watershed Institute
Pacific Shellfish Institute
Padilla Bay National Estuarine Research Reserve
Port Townsend Marine Science Center
Puget Sound Institute
Non-profit organizations
Long Live the Kings
Nature Conservancy
Olympic Coast National Marine Sanctuary
Skagit River Systems River Cooperative
Colleges and Universities
University of British Columbia Fisheries Centre
University of Washington College of the Environment
University of Washington Friday Harbor Labs
University of Washington SAFS
Washington State University Puyallup including the Washington Stormwater Center
Washington State University Puyallup Research & Extension Center
Western Washington University Shannon Point Marine Science Center

Appendix C

Appendix C1:
Inventory of Ongoing and Recently Completed Projects. (provided in an excel file)
Appendix C2:
Descriptions of Ongoing and Recently Completed Projects. (provided in an excel file)

Appendix D:
Summary of the total number and total budgets of projects assigned to each of the 48 Priority Science Actions. (provided in an excel file)

Appendix E:
Inventory of Recommended Studies. (provided in an excel file)

Appendix F:
Scientific reports and paper published since 2011 of relevance to Puget Sound recovery (provided in an excel file)